

**Particle Characterization**  
**Prof. Dr. R. Nagarajan**  
**Department of Chemical Engineering**  
**Indian Institute of Technology, Madras**

**Module No. # 12**

**Lecture No. # 37**

**Particle Relevance of Particle Characterization: Explosively**

Good morning. Welcome to the thirty-seventh lecture in our particle characterization course. In the last few lectures, we have been discussing applications of particle technology to high technology manufacturing industries such as semiconductors and we have been focusing on characteristics of particles that have importance in such applications. Today, we are going to look at one more application of particles, where the specific properties of the particles play a very important role, and this has to do with the fact that particles, because they are a finely divided form of matter, are highly reactive and also have high transport coefficients as we have seen.

When you look at the combination of these two factors, the harmful aspects of particles, particularly in our everyday life, can also be quite significant. In particular, the two aspects of particulate behaviour that are of concern to us are explosions and health effects. When you talk about explosions, what we are talking about here is essentially, dust clouds which can not only initiate combustion, but also sustain combustion and explosion over a long period of time, as well as over large distances. The reason, of course, is that as particle size gets smaller, its burning rate increases.

As we have seen before, you can look at the rate of burning of a particle as being inversely proportional to the diameter of the particle. So, the total time for burning essentially goes as  $d^2$ . So as the particle or droplet diameter becomes smaller and smaller, its ability to burn increases quite rapidly. So, if you have essentially a dust cloud consisting of very fine particles, you can see that the tendency for this dust cloud to ignite and then explode is quite high.

Now, there are many industries in which such dust clouds can form. Some of them are obvious, when you are talking about mining, for example, coal mining is one instance

where the ability of the suspended coal fines in the environment of the mine is a huge risk from an explosion view point. I am sure you have read of periodic accounts and papers, where a mine collapses because of an explosion.

The reason that this happens, is that particularly in a mining operation, there are many sources of fine particles. The process of bringing out the ore, the mining process itself creates many fine particles, and then, the transport or conveyance of these coal particles or other types of mineral particles from the mine shaft to the outside, again involves several potential sources of combustible particles. So, coal mines have always been associated with a tendency for ignition and explosion.

But **there are** virtually, every industry that involves particulates in some form is susceptible to explosions that are caused due to the presence of these fine particles. For example, even wood working. **When you** When somebody is working in wood, they are generating this wood chips, wood burrs, which can catch fire quite easily. Any combination operations, size reduction operations such as crushing, grinding they all involve essentially, the generation of very fine particles.

The same thing happens with polishing or any kind of metal working involves generation of particles. So, the metal industry, plastics, even plastic particles, if they are fine enough can burn quite easily. Pharma industry - we are constantly dealing with extremely fine particles with bio-components to them and these are also quite capable of catching fire and then maintaining the flame conditions for a long period of time.

Chemical industries, obviously, I mean any chemical industry will involve the use of various chemical reagents in powder form, and if you are not storing them and treating them properly, they can easily lead to a fire incident. **So, I mean that** The point is there are literally hundreds of industries in which particles in their fine form are encountered, and you always have to be on watch for potential ignition and combustion type of situations.

Now, the properties of these particles that really lead to ignition and then sustenance of the explosion are things like size obviously, shape, it is quite possible that non-spherical particles are more reactive than spherical particles, if only because they are in a thermodynamically less stable condition. Concentration is the largest variable. When we talk

about any fire that is sustained by finely divided particles in the environment, the higher the concentration, obviously, the greater the propensity for ignition to happen.

Now, when you think about fuel to air combustion, normally, the maximum rate of combustion or maximum flame speed happens, when there is stoichiometric ratio of fuel to air. However, in situations involving particularly, solid fuels like for example, metal fines in air, that is not true. In fact, the rate of combustion as well as the rate of flame propagation are higher for higher ratios of solid fuel to air. So, the greater the concentration of solids in the air, the higher the probability that something will ignite and also, the higher the rate at which the combustion front will move.

There are actually two types of explosion situations. One is called detonation; the other is called deflagration. The difference between the two is, in detonation, the shockwave that is that usually accompanies an explosion travels at the same rate as the flame front. So, essentially, in a detonation by the time, you hear in a sense, the explosion, the flame will already be at your location; deflagration is one in which the shockwave travels much faster than the flame front. So, essentially, you will hear the explosion first before the flame front reaches you, but in both cases the flame fronts are moving very fast essentially at the speed of sound.

So, you do not have really much time to react. By the time you hear an explosion or you see a flame front, it is probably too late. So, a lot of focus really has to be on prevention. So, for example, some other things that are done, if you take a coal mine for example, it turns out that methane gas, when it is present can accelerate the reactions leading to burning and ignition.

The percentage of methane that is present in the environment has a huge effect on the probability or possibility of ignition happening. In fact, in the old days, miners used to take a parrot with them into the mine. The reason for that is, if a parrot inhales some methane, it will die. So, they keep looking for a sign that the parrot is suffering; as soon as it starts to show some discomfort, it means there is more methane than normal in the atmosphere and it is time for all the miners to get out.

Also, in something like a coal mine, your options are limited. I mean you have to mine the coal and you have to bring it out. I mean that is the reason that the coal mine operates. So, what can you do to reduce the sources of fire? Well, the first thing is again

to minimize the concentration of fines in the environment. So, any time you are worried about an ignition slash explosion situation associated with particulate fines in the atmosphere, the best strategy is to minimize the source, reduce the concentration of these fines and that can be done by essentially improving the process. I mean instead of using big hammers to break the rocks and get the minerals out, maybe, there is a smarter way to do it; maybe, you can use less force, more better directed; maybe with some containment; maybe you can have some vacuum that sucks up the particles or some air flow that directs the particles to go to a less critical location. So, that type of process investigation and improvement, in order to minimize the source is the first thing you should consider. The second is containment; containment works not in a coal mine, but if you have equipment, for example, a grinder that is constantly generating particles, then you can at least think about containing it, isolating it so that these particles do not propagate out into the rest of the process.

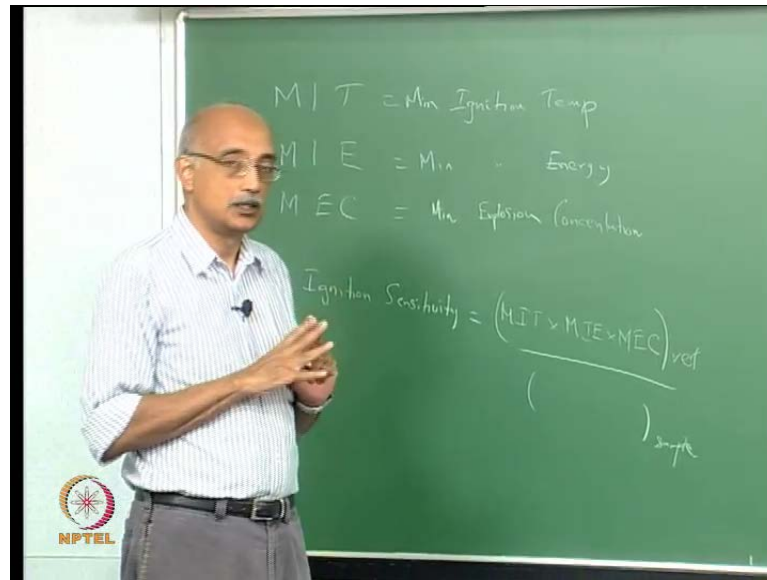
So, isolation is a method that at least localizes the threat of ignition and combustion. So, that is a second strategy that is commonly employed. The third is venting. Again, you have to design and in this case, it can work for a coal mine as well as for any process equipment. As soon as the fines are generated, they must be getting either sucked up and exhausted or they must be actively suppressed in some manner essentially, by using air flow. So, proper venting can help prevent a lot of these ignition type of situations from happening.

Suppression is another good strategy. Essentially, this can be done by for example, pumping in inert gasses so instead of providing an oxidizing environment as long as it is a enclosed or enclosable piece of equipment or 2 link, you can essentially pump in nitrogen or inert gases and provide a non-oxidative atmosphere and that again can minimize the propensity for ignition and combustion.

So, there are a lot of interesting aspects of how particle behaviour affects ignition and explosion tendencies in such systems and one of the key things that we try to quantify is the ignition properties as well as the explosion properties of a particle suspension in fluids. There are again standards, agencies, testing agencies which have defined these parameters or properties. Now, many of these properties are not fundamental properties. You cannot relate them back to the molecular structure of the particle.

They are essentially, empirical properties that depend on the test method and for that reason, a lot of effort has been put in to standardize the test method so that the results from one lab become comparable to results from the other lab. So, in terms of the ignition tendencies of dust, the standards that are used, there is mainly three of them.

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Just remember them as MIT MIE and MEP, where MIT stands for Minimum Ignition Temperature, MIE stands for a Minimum Ignition Energy and MEP stands for Minimum Explosion. This should be MEC, Concentration. So, the way these are defined, the Minimum Ignition Temperature is determined by taking a sample of the dust injected into a heater chamber and slowly increase the temperature until you reach a temperature at which the powder will essentially self-ignite. So, this is without the addition of an external oxidizing source. It is also called the auto ignition temperature. So, it gives you a temperature at which the ignition will happen regardless of how oxidizing the environment is.

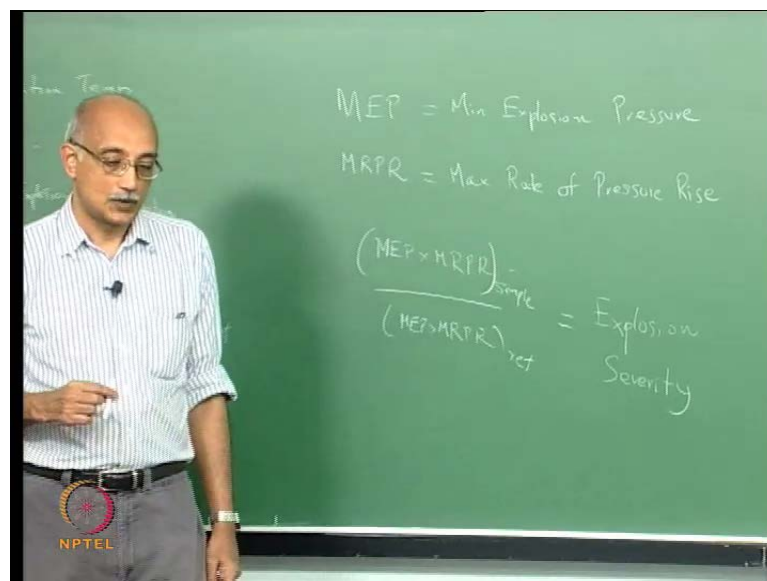
Minimum ignition energy is determine by essentially, keeping the temperature at room temperature, injecting the powder into the chamber and providing an external source of energy. This could be like a spark discharge and slowly ramping up this energy input until ignition happens. It is a minimum external energy input that can drive ignition to happen.

Finally, the minimum explosion concentration is where you keep the chamber temperature at the minimum ignition temperature, but lower the concentration until ignition stops happening. So, it gives you a value for the threshold concentration or minimum concentration at which ignition will happen.

So, these three parameters together provide actually an index for ignition sensitivity of the particulate mixture. So, ignition sensitivity is defined as the multiple of MIT times MIE times MEC for a reference dust divided by the same product for the sample. Under consideration and the reference dust is traditionally taken to be Pittsburgh coal dust. So, this is a dust sample that has been extracted from the Pittsburgh coal mines and distributed to various labs around the world and this is kept to use as the standard to compare your sample against.

Now, similarly, when we talk about explosion there are two parameters that govern how severe the explosion will be when it happens.

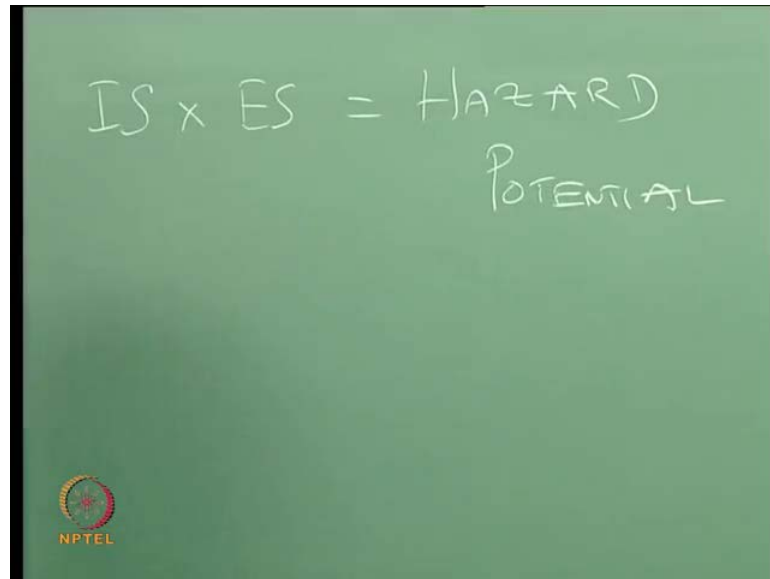
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These are defined as MEP and MRPR, where MEP stands for Minimum Explosion Pressure and MRPR stands for Maximum Rate of Pressure Rise. So, these terms refer to measurements of how severe the pressure release is, when explosion happens. What is the minimum pressure release, when the mixture explodes and maximum rate of pressure rise then refers to once you have an initial pressure that is associated with the explosion, how rapidly does the pressure rise subsequently.

So, here again, if you take the product of MEP times MRPR and then take the ratio of the same parameter MEP times MRPR. In this case, the reference values are reversed in order. So, the sample goes in the numerator and the reference goes in the denominator. Again, Pittsburgh coal dust is used as the reference. This ratio then is defined as explosion severity.

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Now, if you take the product of ignition sensitivity times explosion severity, this then is termed as the hazard potential that is associated with that particular mixture. So, as a safety engineer, what you should try to do is evaluate these parameters associated with ignition of the mixture, evaluate these parameters that are referencing the process of explosion and its aftermath, then evaluate the hazard potential essentially as the product of the two and then you use it as hazard potential with various purposes. One is we can rank different processes or different equipment or different locations. In fact, all coal mines, all over the world have been assessed using this technique and their hazard potential has been identified.

So, people, before they go into work in a mine need to be told, what the hazard potential of that mine is compared to other mines around the world. So, that is one way to use this number. It is to make both the miners as well as the managers and the owners of the mine aware of the risk involved in running a process in that mine. The other way that it can be used is for process improvement. Once you have established a hazard potential, as the

processes operating today, you can try and make changes to it to continuously reduce the hazard potential.

So, you do that by addressing the ignition part as well as by addressing the explosion part and try to obtain a net result or value of the hazard potential that you try to drive lower and lower. So, the key thing here is that we are able to quantify these parameters. Now, if you look at these values and you relate them back to particle characteristics, as you can imagine the ignition parameters particularly, the minimum ignition temperatures, energy as well as concentration are all going to be related once again to the size and shape of the particles primarily and also to that nature their chemical aspects, their physical structure is going to play a role, properties such as density will play a role because if you have a particle that is heavier, it is more likely to settle and therefore, become less of a concern than a particle that stays air borne. For example, so, the Stokes number will become an important parameter because in this case, you want high Stokes numbers because higher Stokes number implies more inertial behaviour. So, these particles are more likely to settle and again settled particles are not a concern because when settling happens whether in process equipment or in a coal mine, it tends to happen in its critical locations. For example, in a coal mining shaft, most of the inertial deposition will happen around the walls of the shaft or the floor and so, these particles will then not really participate in any explosion process that happens subsequently.

Similarly, in a grinder or a crusher or a milling equipment, any particles generated that are large enough that they have significant sedimentation velocities are not an issue from flame propagation point of view. Again, the reason that it is important for particles to stay air bond is that dust explosions in particular involve a primary process and a secondary process.

The primary process is the first ignition that happens, but then that is likely to be of small time scale and if that is all that happens, it will eventually die out, but if simultaneously the particles are set in motion, then this energy is essentially carried from one front to another. So, then the flames start to propagate and the dust explosion become something that this sustained over a long distance.

So, the ability of the particles to remain air borne and to be transported over long distances, it is very important for ignition to be converted to a sustainable explosion. So,



a lot of interesting things to think about that generation of fine particles is really the big problem here not the generation of particles in general. Coarse particles, we can deal with. How to get them to settle? I mean, all we need to do is clean the floor; mop the floor once in a while and you can remove these particles that are settled. Similarly, you wipe the equipment walls periodically and you will clean off any particles that have settled. So, they never become air borne. It is the particles again in that intermediate size range that are in the most difficult to deal with.

Because extremely fine particles like in the nano range again because of the high diffusional characteristics will eventually find a solid surface and stick to it. So, we do not really need to worry about those too much. It is the particles in the sub-micron to 1 micron to 2 microns size range that are the most dangerous in terms of ignition and explosion as well.

So, we have been talking about essentially solid particles and their ignition, explosion characteristics so far. If you think about liquid droplets, when you of what we have been talking about would still apply. Now, liquid fuel combustion is obviously very commonly used in many applications, starting from your automobiles to jet planes to whatever.

The key thing when you are trying to burn a liquid is that it burns better again when you break it up into droplets. So, it is always tempting to atomize liquid fuels because atomization, which is essentially the process of breaking up a continuous film of a liquid into fine droplets. It is a process that has huge advantages in terms of improving the combustion efficiency. For example, in satellite propulsion applications, ISRO uses liquid kerosene as the fuel.

They have devoted a lot of research to the best processes for atomizing this liquid kerosene so that when it gets introduced into the combustion chamber, it will burn with the highest efficiency. They want to use the minimum of the fuel, they also want to minimize the combustion time because satellites are getting smaller and smaller.

When you go to Nano satellites or Pico satellites, the total time that is available to you for combustion is of the order of Nano seconds and Pico seconds. So, combustion and energy release has to happen almost instantaneously. In order to do that, you have to make that droplets as fine as possible. So, that is one aspect, where this finely divided

form actually presents huge advantages. If you take liquid fuel and convert it to an extremely fine droplet form, then combustion will proceed at very high rates again because the time required for combustion drops rapidly as the size of the droplet decreases.

However, when this atomization or aerosolization happens unintentionally, then again it presents the safety risk. For example, in conventional chemical engineering plants like any process that you are trying to draw energy from one fluid and pass it on or draw energy from one surface and pass it on to another surface, you use heat transfer fluids. Now, these heat transfer fluids are selected primarily on the basis of their heat transfer coefficients. You want to use a heat transfer fluid that has a very high heat transfer coefficient so that this transfer or exchange of heat can be done again with the maximum efficiency.

Now, some of the other properties, you look for are the operating pressure, the operating temperature range and obviously, the heat transfer coefficient of the fluid has to be such that for the range of pressures in operations and for the range of temperatures in operation this fluid will continue to transfer heat effectively. Cost is an important aspect because it is not an unconstrained problem. you can always find an excellent heat transfer fluid but, it may be too expensive for you. So, you are trying to find a heat transfer fluid which has acceptable heat transfer properties, but also acceptable cost.

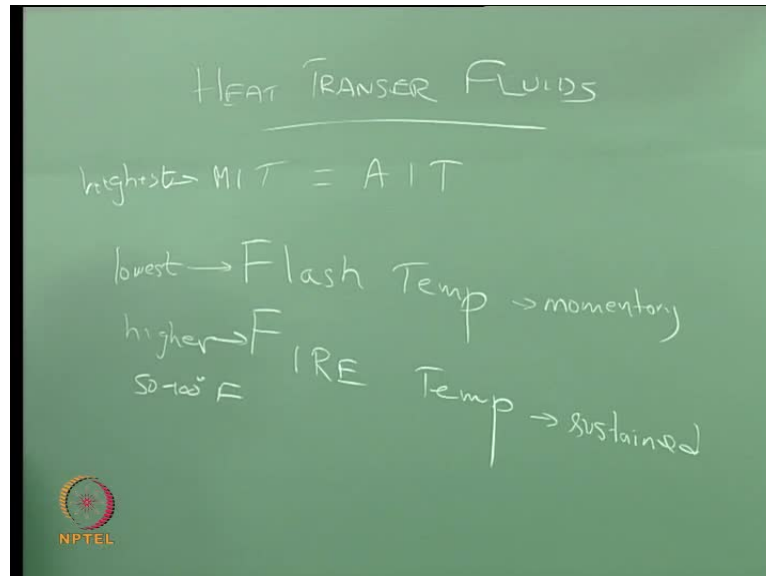
The other aspect you would consider is equipment, I mean, the materials of construction. The heat transfer fluid you choose should not be such that for example, it corrodes the equipment of the materials that you are using. The compatibility between the heat transfer fluid and the materials used in the process must be investigated as well.

The other thing is maintenance. The fuel or the fluid that you are using must not be such that it requires frequent taking down of your heat exchanger equipment for cleaning and maintenance and so on. This is again a compatibility issue. The fluid should not be allowed to form scales, for example, on the heat exchanger tubes. The scales that form may take a lot of time and energy to remove, in order to again reclaim the heat transfer efficiency that we had, originally, when the process was setup.

So, these are all conventional aspects of selecting a heat transfer fluid and obviously, safety is another important consideration. Now, when we test heat transfer fluids for

safety, there are really 3 parameters that are looked at during the selection process. and they are

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So, this is particularly for heat transfer fluids. Again, the first one that we had design that we have defined for solid particles that is the minimum ignition temperature, which is also known as the auto ignition temperature is of relevance to liquid fuels as well or gaseous fuels. So, this refers to a temperature, where the fuel will burn spontaneously without an external source of energy, but there are two other temperatures that are also of interest here.

First is flash temperature and the other one is flash temperature and fire temperature. A flash temperature is defined as the first temperature at which the fuel generates sufficient vapour to sustain momentary combustion. Whereas, the fire temperature is defined as the first temperature at which the fuel generates sufficient vapour pressure to support sustained combustion. So, the difference between them is, this involves momentary combustion whereas, this references sustained combustion.

So, obviously, the flash temperature is the lowest of the 3; the fire temperature compared to the flash temperature is higher and it can be higher by as much as 50 to 100 degrees F and the auto ignition temperature is the highest. So, every heat transfer fluid is ranked in terms of these 3 temperatures and obviously, you try to choose a heat transfer fluid that has the least flash temperature, least fire temperature and least auto ignition temperature.

Now, this conventional approach to selecting a heat transfer fluid based on safety considerations has one big problem. You are assuming here that the fuel the fluid whether it is liquid or gas, particularly liquids are flowing essentially as continuous films. These definitions of ignition temperatures reference a continuous film of liquid that is flowing, but in reality what happens. The heat transfer fluid is getting sprayed into the chamber.

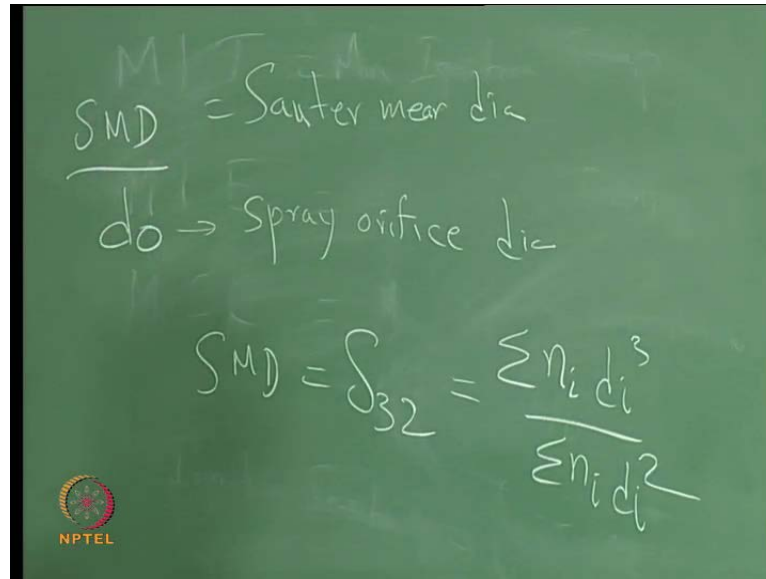
Now, as that gets sprayed, it has a tendency to breakup into droplets especially because we are pressurizing the spray in order to achieve a certain velocity. So, the higher the pressure at which you are spraying the fluid, the greater is the velocity of the fluid as it exits the nozzle and the greater the velocity, the higher will be the shear rate at the interface between the liquid fuel and the air that is surrounding it. Now, a higher shear rate essentially implies more instability at the interface between the air and the fuel.

Higher instability implies more breakup of these the film of a liquid into droplets. So, as you pressurize and spray these liquids that are used as heat transfer fluids, they have a tendency to breakup into fine droplets. So, that is again good from a heat transfer view point because for the same volume of the fluid, you are getting much more heat transfer area now, but from a combustion safety view point, we are again back to the situation we had with the solid powders because due to this atomization or aerosolization, this liquid sheet is now getting converted into fine drops of liquid.

Ignition can happen at temperatures far below this flash temperature because discrete droplets will burn much faster compared to a continuous sheet of liquid. So, it becomes important then to define a new safety parameter. You have to relate the aerosolization characteristics of the liquid to process parameters.

A lot of work has gone into this. For example, Texas a and m university for example, has a safety center, which has probably taken the lead in terms of looking at this problem and trying to develop a correlation between properties of the fluid and the operating conditions to its potential for ignition.

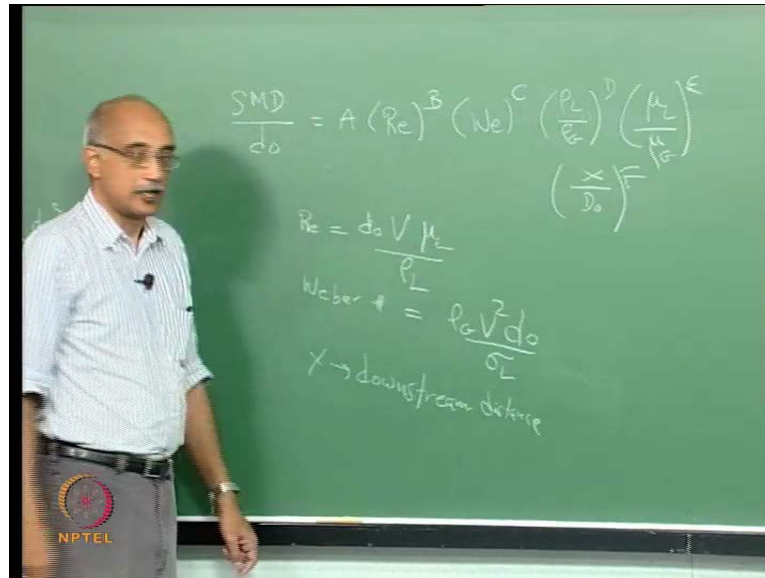
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They have developed a correlation of the following form. They have related the diameter of the droplet that results from this atomization process to flow properties like the Reynolds number, Weber number and so on and the correlation is of the following form. They have taken the sauter mean diameter and non-dimensionalised it with respect to the spray orifice diameter.

So, here,  $d_o$  is the spray orifice dia, SMD stands for Sauter Mean Diameter and the Sauter Mean Diameter is also defined as  $S_{32}$  and it is defined as summation of  $n_i d_i^3$  cubed over summation of  $n_i d_i^2$  squared. By the way, this should be  $S_{32}$  not  $S_{23}$ . So, it is a ratio of essentially the total volume of the liquid material divided by the total surface area that you obtain. So, the smaller the SMD value, the higher the ignition potential; the smaller the SMD value, the smaller is the droplet that results from the atomization process. Therefore, the burning potential is much higher. Another way to look at it is for the same volume of liquid, the most surface area is created when the SMD value is low. A low SMD value implies that you are creating a lot of surface area for the same volume of liquid and that is why the explosion potential is high.

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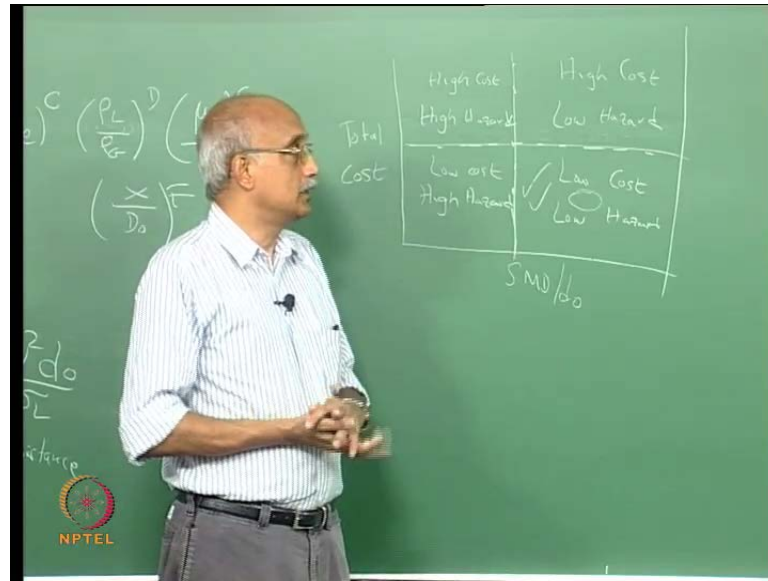


So, you take this ratio SMD to  $d_0$  and you relate it to various process parameters. SMD over  $d_0$  equals some  $A$  times Reynolds number to the power  $B$  times Weber number to the power  $C$  times  $\rho_L$  by  $\rho_G$  to power  $D$  times  $\mu_L$  by  $\mu_G$  to the power  $E$  times  $X$  over  $d_0$  to the power  $F$ . Here, the constants  $A, B, C, D, E, F$  are essentially obtained by doing lot of experiments and doing multiple regressions.

The Reynolds number is defined as  $d_0$  times  $V$  times  $\mu_L$  over  $\rho_L$ , where  $V$  is the exit velocity of the liquid from the nozzle,  $\mu_L$  is the viscosity of the liquid and  $\rho_L$  is the density of the liquid. So, the Reynolds number really refers to the flow of the liquid. Weber number  $We$  stands for Weber number and this is defined as  $\rho_G$  times  $V$  squared times  $d_0$  over  $\sigma_L$ , where  $\rho_G$  is the density of the gas that is in contact with the liquid interfacially,  $V$  again is the exit velocity from the nozzle,  $d_0$  is again the spray nozzle diameter and  $\sigma_L$  is the surface tension of the liquid.

Again,  $\rho_L$  by  $\rho_G$  is the ratio of the densities,  $\mu_L$  by  $\mu_G$  is the ratio of the viscosities,  $X$  is the downstream distance which is non-dimensionalised with respect to the nozzle diameter. So, by using this correlation, what we can do is for a given set of properties on the right hand side, for a given nozzle diameter, velocity, liquid properties, gas properties, we can actually estimate the droplet size that results from the atomization process as a function of distance away from the nozzle.

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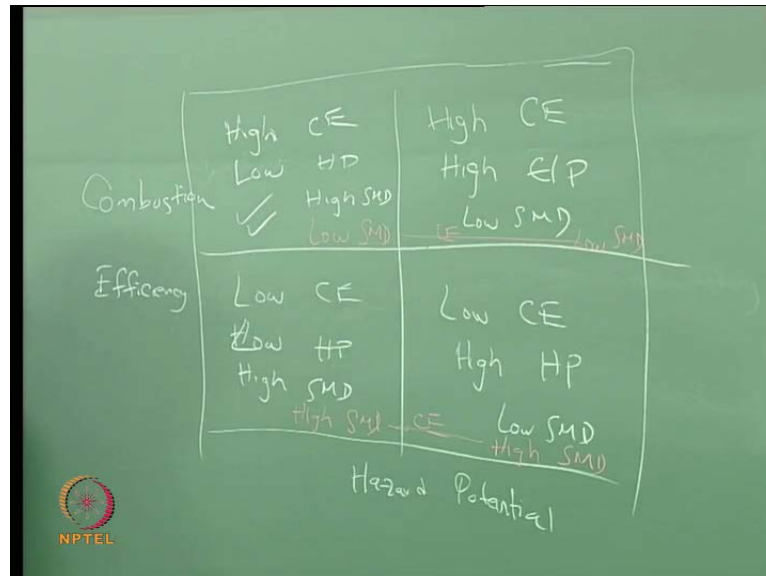
So, how is this information useful to us? So, once you have calculated this sauter mean diameter for your specific operating conditions, you develop charts of the following form. On this axis, you plot SMD over  $d_0$  and in this axis, you plot total cost. As a process engineer, these are one of the first charts that you will generate. Now, if you are on this quadrant, left hand side lower quadrant, what does it mean? This is low cost, but the sauter mean diameter is low in this quadrant. So, it is high hazard.

If you look at this quadrant, it is high cost and high hazard potential. If you look at this quadrant, this again is high cost, but low hazard because your sauter mean diameter is higher. This quadrant represents the best case scenario, low cost and low hazard. So, you should try to design your process such that you operate in this quadrant. Choose your heat transfer fluid in such a way that the resulting hazard potential is low, but at the same time your cost is also minimized. Now, this somewhat of a deterministic view of things, but there are a lot of uncertainties.

So, these boundaries are not always clear; probably, draw them as dashed lines. So, that means that if you operate too close to one of these boundaries, it is quite possible that you can trip over from one side to the other. So, the message behind that is, do not try to operate near any of these boundaries. Try to operate as much in the center as possible so that even if there are some slight uncertainties in your estimation of the various parameters, you are still safe. You are not going to fall over from one quadrant to another

quadrant. So, this quadrant based approach for process design is something that is widely employed in heat transfer or industries involving heat exchanger equipment.

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Now, another way that you can do this is **by looking at** on the one axis, you can plot hazard potential and on the other axis, you can plot combustion efficiency. Now, if you look at it this way, again this quadrant has high combustion efficiency and low hazard potential, this one has low combustion efficiency and high and low hazard potential. Here, you have high combustion efficiency and high hazard potential and in this quadrant, you have low combustion efficiency and you have high hazard potential. So, here obviously, the quadrant that you want to work in is this one. It has high combustion efficiency and low hazard potential, but how do you achieve that.

In terms of the sauter mean diameter, what does this mean? We know that any time you have high hazard potential, it implies low sauter mean diameter whereas, a low hazard potential implies high SMD, but that is based up on simple hazard potential considerations. Supposing, I were to look at that in terms of combustion efficiency. Is that still true? To get high combustion efficiency, what do you need? You need low SMD. So, low SMD, here also, you have low SMD and here, you have high SMD and here also, you have high.

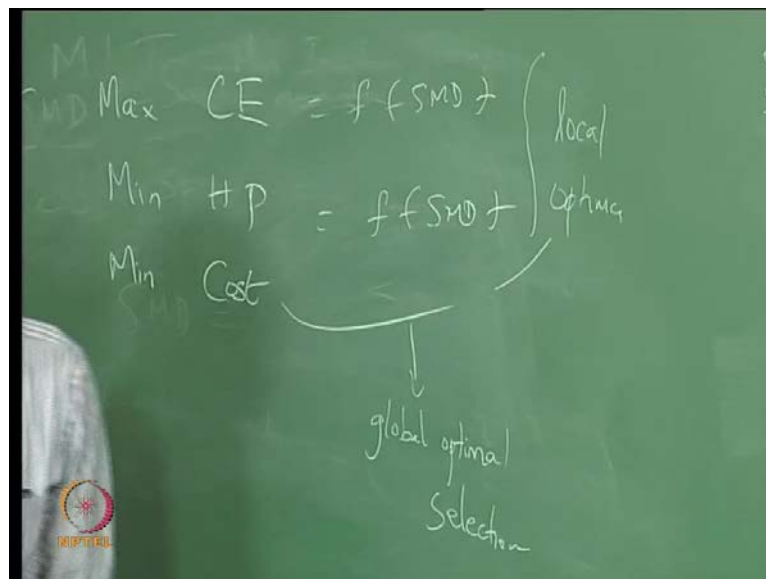
So, this is based upon combustion efficiency considerations whereas, our previous designation was based upon hazard potential evaluations. Now, when you look at this



together what does it mean? You are getting some conflicting messages here. If you want to only maximize combustion efficiency, you should try to operate with a low sauter mean diameter. If you want to operate with high or low hazard potential, you should try to operate with the high sauter mean diameter.

So, this is a classical constraint optimization problem. As an engineer, your job will be to take a look at these two conflicting requirements and arrive at the best or optimum selection of heat transfer fluid that gives you the highest combustion efficiency at the lowest hazard potential. Of course, if you want to turn this into a 3-dimensional plot, you can also bring in total cost as another axis here. So, the third constraint on your problem will be cost minimization. Is it possible to do? So, you have three requirements which are at least somewhat in conflict with each other and you have to be good enough or smart enough to be able to meet all three requirements.

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So, you want to maximize combustion efficiency, you want to minimize hazard potential, you want to minimize cost and when you talk about cost, it is not just the purchase cost of the heat transfer as the fluid, but the long term operating cost of the equipment. So, you have to project how much it is going to cost to purchase appropriate materials, how much it is going to cost to maintain the equipment and so on and all of that has to be taken into consideration so that you do not only look at the one time or capital cost of purchase, but also the recurring cost of running the equipment over time.

The way you do this is again quantification. You should try to obtain an expression for this as a function of the sauter mean diameter and then similarly, for hazard potential as a function of the sauter mean diameter. Cost of course, is not necessarily related to the sauter mean diameter, but these two are. So, essentially, the way you would do this is try to optimize the sauter mean diameter based on these two considerations.

**But do not go for a** I mean it would not be a global optimum. Essentially, you can define various optima and then among them, you choose the global optimum based on cost considerations. (Refer Slide Time: 45:57) So, this will lead to local optima and this plus this will lead to a global optimum selection of a heat transfer fluid. So, as you can see this whole process of ignition, explosion, combustion whether it involves solid particulates or whether it involves droplets, involves many key aspects of particle characteristics that we need be aware of, we need to be able to measure. See, for example, the way they actually derived this correlation is by doing measurements of the sauter mean diameter as a function of various process parameters.

You would not even be able to do that unless you knew how to measure sizes of droplets. So, size measurements becomes a very important aspect of this exercise and it has a very practical impact and it can wind up saving lives, if you do it with the right way. Similarly, the ability to measure properties such as the shape of a particle, the rate of movement of particles, all of these is very important as a process design engineer in order for you to setup and operate a process that gives you the product that you are looking for, but at the same time minimizes any safety hazards and other exposures that might be there in the process.

Now, as I was mentioning earlier, there are two harmful aspects of finely divided matter that we need to be aware of. The first, we have dealt with today, ignition and combustion; the other aspect is actually two fold. One is the environmental aspects. How do atmospheric particles affect the environment? We are all aware of global warming and all those phenomena that are going on. What role do particles play in this? That is the key understanding we need to have. The second aspect is human health. As humans, we are constantly ingesting particles into our system, whether it is through breathing or swallowing or even through our skin and all of these, will have a tendency to affect our health and hygiene and so on.

Here again, as you can imagine the particle's properties that are going to have direct impact are shape, size, transport characteristics, chemical characteristics, dissolution characteristics, diffusion characteristics. So, the basic properties that are of importance remain the same. What we are going to discuss is a different end effect that is the result of these basic properties. So, we will stop at this point. Any questions on what we have talked about today? I shall see you in the next class.