Environmental Air Pollution

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Interpretation and Particle Size Distributions
Lecture 6

That should be there. We will go beyond what we have been saying last time in terms of the particle size and things like that. We have to now slightly go more into the particle sizes. The reason is that particle size is not uniform, unfortunately. There will be lot of variability there. We will spend some time on the interpretation and to see real the how the data in atmosphere really looks like.

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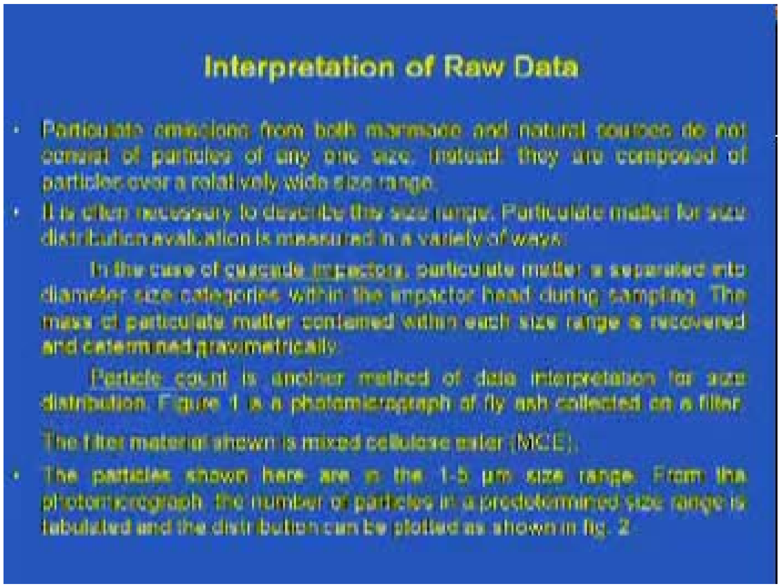

Interpretation of Raw Data

- Particulate emissions from both manmade and natural sources do not consist of particles of any one size. Instead they are composed of particles over a relatively wide size range.
- It is often necessary to describe this size range. Particulate matter for size distribution evaluation is measured in a variety of ways:

In the case of cascade impactors, particulate matter is separated into diameter size categories within the impactor head during sampling. The mass of particulate matter contained within each size range is recovered and determined gravimetrically.

Particle count is another method of data interpretation for size distribution. Figure 1 is a photomicrograph of fly ash collected on a filter.

The filter material shown is mixed cellulose ester (MCE).

- The particles shown here are in the 1-5 µm size range. From the photomicrograph, the number of particles in a predetermined size range is tabulated and the distribution can be plotted as shown in fig. 2

The particle emissions from both manmade and the natural sources do not constitute a particle of any one size - that is what we said. Last time we were just sticking to one particle. Instead they are composed of particles of a relatively wide size range. It is often necessary to describe the size ranges particular particulate matter of size distribution evaluation is measured in a variety of ways. We have to give the size distribution like that: What is the mean of the particle size? What is the standard deviation of particle size? And things like that.

Have you heard of the Cascade Impactor? No. What happens is because when it comes to the matter of interest, either as when controlling the particulate matter or you are trying to see what the particulate matters in the atmosphere are. The size is very important especially because of the health point of view and also the way you have to design a system - when you want to design a system which particle size you want to remove. The system which is somehow segregates particle size; we try to use the advantage of another thing called Cascade Impactor. It is based on the inertia.

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Suppose, I have a plate here and my air flow is coming onto this. Then we have the particles of different sizes: some small, some big, some small; many are small and some big; most of them are big particles. All the particles as well as the gas stream both have inertia. Who has more inertia? The particle has much larger inertia whereas the gas has no inertia. Gas since they have no inertia, they will continue to... the gas streams will try to turn and follow this; this will go beyond this plate. Even amongst the particles which will have more inertia? The larger particles will have more inertia. The larger particles, what will they do? They will tend to separate out from the stream because of the inertia they will try to travel in the same direction. This small particle, which you see, will escape and try to go along with the gas stream. The larger particles, which you see here, goes and hit whatever plate you may have; it may head to the plate.

Then to capture this particle you may sometimes, if you wish, you can put little oily surface. Once it is hit because you want to separate out these particles that hits and the smaller particles, like for example, this particle will continue to move out; this particle - this smaller one - will continue to move out along with the stream; the larger particles will be stopped just based on the inertia and then I can have a filter here. I will see all my fine particles that will be collected here. So I can separate them. This is called Cascade Impactor. It is cascading in fact; then it can go to here, if I want to further fractionalize that one, I can make it further, (Refer Slide Time: 04:32 min) a further kind of plate, so that some particles will stay here, some will continue to go along. So I can even find the particle size distribution.

Sometimes, the same kinds of concepts I use while controlling certain particles and sometimes measuring the particles in the mid air. In case of the Cascade Impactor the particulate matter is separated into the diameter size categories within the impactor head during sampling (Refer Slide Time: 05:01 min). The mass of the particulate matter contained within each size range is recovered and determined gravimetrically. You can measure these particles or you can measure these particles. Then that most of the equipments what you see will be like, for example, PM 10 analyzer; PM 10 sampler basically.

Time permitting I might show you that picture also. In PM 10, all the larger particles will be stopped and only PM 10 particles will be retained here. The particle size is less than 10 aerodynamic dynamiters. You can do the calculation. You can design the things because you know the inertia; you know the general structure of your particles in the atmosphere.

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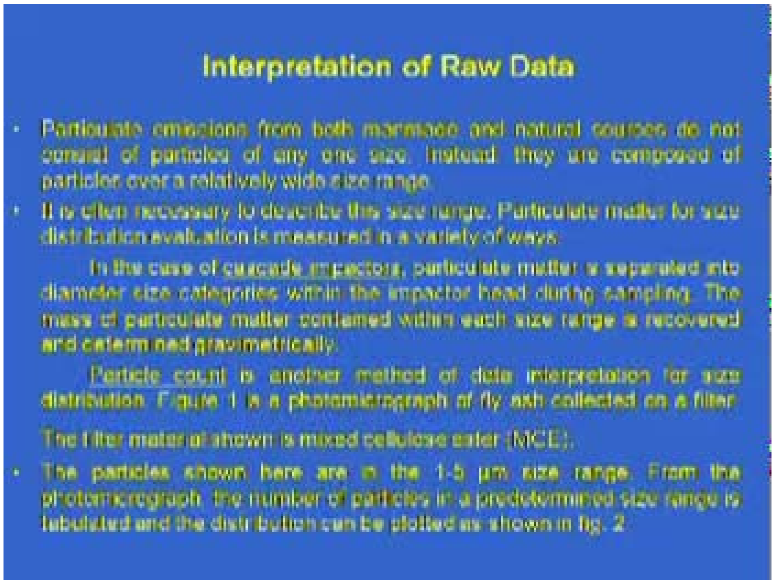

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Particles count is also a very important thing. Some of the medical people prefer not the mass, but the number of particles that are there. There is another method to data interpretation for the size distribution; we will show you the figure 1 in a moment. I will show you the fly ash collected on a filter paper.

The filter paper material also depends on what kind of material you have and the larger reason for a particular type of material where you have the filter paper can be many reasons. Suppose, you are doing a sampling inside the stack and cellulose is very ordinary paper. Suppose, the stack temperature is high and you have even made a very sophisticated sampler that you only want to sample PM 10 particles coming from the stack. What will happen to this particle? Inside the stack temperature could be high. This cellulose will completely burn out; you did not get anything; in that case you might like to use Teflon. Sometimes you are doing suppose a very sophisticated test; you want to find out the metals in the atmosphere. This filter paper where you are collecting itself has lot of background heavy metals and metals; then, it becomes a little problem; because, background pollution will be interfering so much with your actual thing which you want to measure, so then your choice of filter paper can be different.

I will be drifting, but that is fine. For example, you want to measure the silicon. Suppose you are using the quartz filter paper, you will never be able to find the silicon in the air, if you are using a quartz filter paper. Quartz is all 90 percent silicon and then you will never be able to find it. That also decides as to what kind of filter paper, depends not on the particle size, but in what way you want to characterize the particles; so that also decides the filter paper. The particle shown in the figure is in the size range 1 to 5 micron. From the picture, we will show the number of particles in predetermined size range is tabulated. I will show you the figure in a moment.

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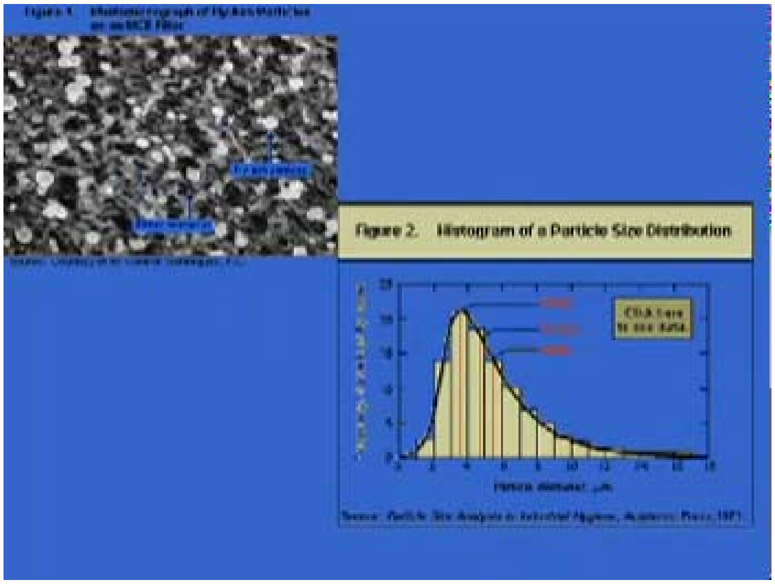

Figure 2. Histogram of a Particle Size Distribution

Source: Particle Size Analysis in Industrial Hygiene, Academic Press, 1971

That is how we analyse the data. Here what are you seeing? Here the white dots you see are the fly ash particles, and these are the filter particles; so all the black things. When you look at the microscopic you can see these particles and in fact you can also determine the particle sizes through some of the equipments. What they do some of the equipment - I am forgetting the names - they will quickly see the particles. They make some kind of fringe, the machine, through the lights and the mechanism they have. Then, that particular size of the fringe along the particle is measured, you know, through electronic means and something like that. The other way to show the data, which we are getting the particles, is also needed because we need to say sometimes because the interest may lie in the larger particles. Then you have to say how much quantity the larger particles because you have to design equipment for the larger particle size.

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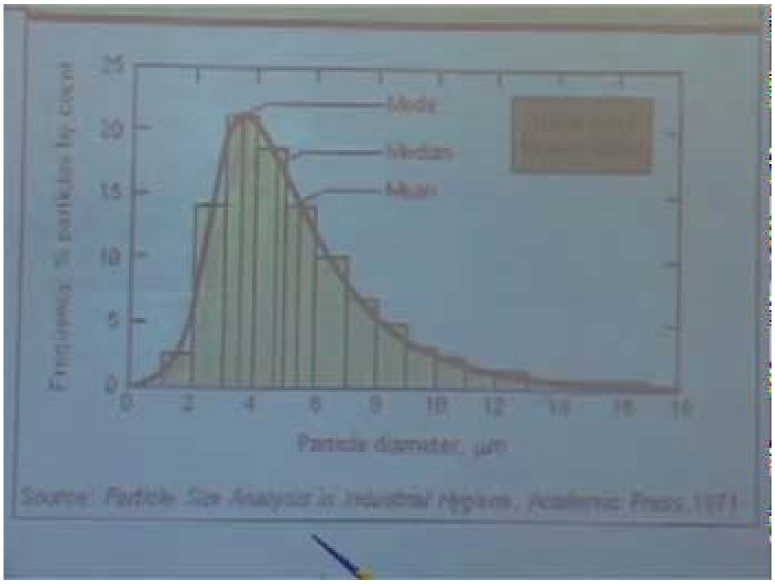

Sometimes for a specific particle size maybe you want to just remove these particles. The loading can be different for the larger particles, smaller particles and this thing. This is simply a frequency plot presented by counts, it says. Now, the number of particles, that by counts, that will be in that category. The particle diameter and then obviously we know that well here we all understand mode, we understand the median, we understand the mean. There is nothing new about this one.

I think what you need to understand from here is suppose you have the very wide range and not quite wide. Let us say we have something like: 1, 1, 2 and then you have 3, 3, 4, 4.5 and 5, 5.5. You have data points - 13 and 15. You have to be a little careful sometimes. What you want to take is you want to take the mean or the median here. You want to point out the average particle size. You have to be careful sometimes that you have to in such data set you have to take the median because that is much robust. Central point rather than this thing because you can see these points which are really not quite there, but they will influence your arithmetic mean hugely. Sometimes we make wrong decisions; then, we will say most of the particles are sitting somewhere at 7 and you see we have no particle at 7. Not even factor one single particle; your average may come out to be 7 because you have the large numbers here. If you take the median you can suppress the effect of the large number of observations and things like that.

The other thing which we need to see is quickly is the skewed nature of the curve. This is skewed to left or skewed to the right? Skewed to the right. Always remember because it has the extended tail on to this side; so it is skewed to the right. We are this mentioning here is in fact most of the time, 99 percent of the time, when you look all the environmental data not only in air pollution but in water pollution, soil pollution, when you have these numbers of measurements, when you plot them, you will find that this data is skewed to the right. Such distribution obviously is not the normal distribution. In fact, this is what we call Log Normal Distribution. We should little bit be aware of that because data are skewed to the right. That is the skew thing which I wanted to show. Obviously, the other way I can plot the same graph is that I can take the logarithmic of these values and that is what has been done to show that this data... not quite anyway.

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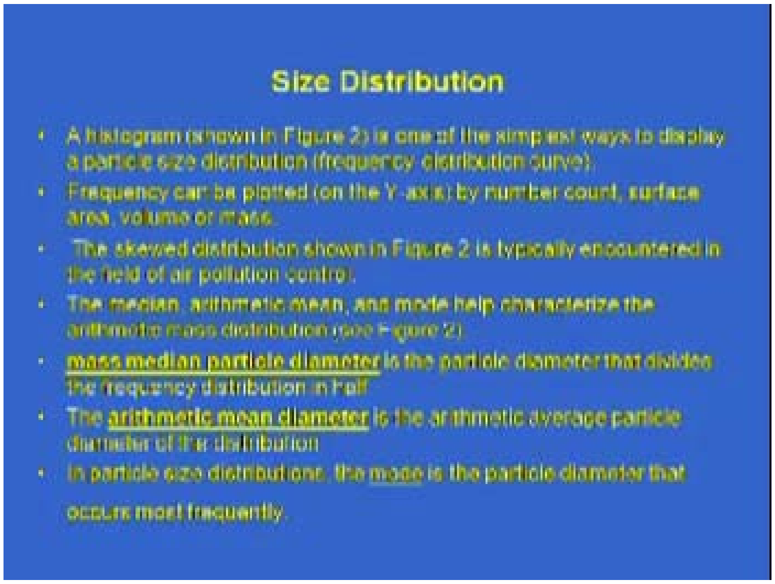

Size Distribution

- A histogram (shown in Figure 2) is one of the simplest ways to display a particle size distribution (frequency distribution curve).
- Frequency can be plotted (on the Y-axis) by number count, surface area, volume or mass.
- The skewed distribution shown in Figure 2 is typically encountered in the field of air pollution control.
- The median, arithmetic mean, and mode help characterize the arithmetic mass distribution (see Figure 2).
- mass median particle diameter is the particle diameter that divides the frequency distribution in half
- The arithmetic mean diameter is the arithmetic average particle diameter of the distribution
- In particle size distributions, the mode is the particle diameter that occurs most frequently.

Skewed Distribution shown in figure 2 is typically encountered in the field of air pollution control; not only air pollution control, even if you have the data from the water pollution control. Any guess as to why the data will be Log Normally Distributed? One of the reasons is that we are not likely to get negative numbers. As a result the things have the tendency towards the right side and that is why the data is always skewed to the right. The median arithmetic mean we all understand that the mass median particle diameter, is the particle diameter, that divides the frequency distribution in half; the arithmetic mean we all understand and the and the mode is of course most frequently encountered particle.

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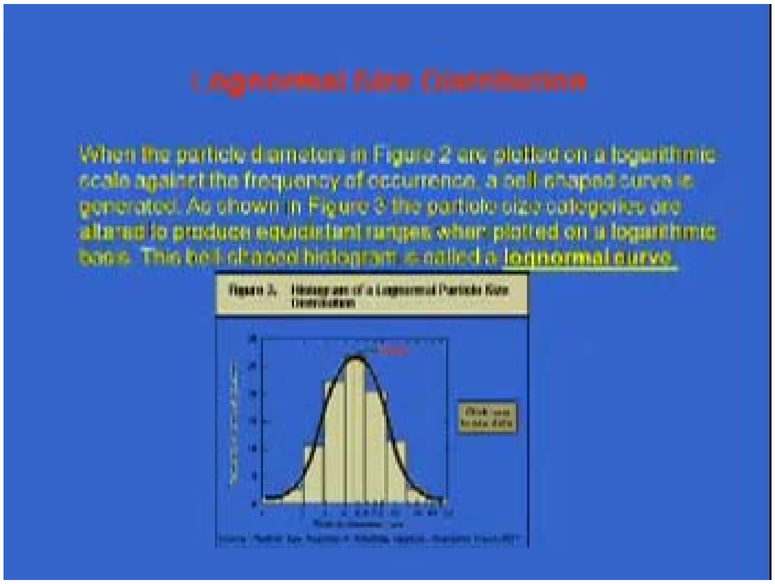

Lognormal Size Distribution

When the particle diameters in Figure 2 are plotted on a logarithmic scale against the frequency of occurrence, a bell shaped curve is generated. As shown in Figure 3 the particle size categories are altered to produce equidistant ranges when plotted on a logarithmic basis. This bell shaped histogram is called a **lognormal curve**.

Figure 3. Histogram of a Lognormal Particle Size Distribution

What I really want to show is this is what you understand is the right time to discuss this. The same data set, but you what you see here is that we have taken the logarithmic here. Then you see the distribution becomes very nice and everything tend to be more or less coincide – mean, mode, median and this is how we want to sometimes distribute the data. In fact, whatever the analysis, sometimes we need to do in the field of environmental quality - normally; we should deal and treat the data log normally, because if you do something normally there will always be question in the exam or something or you are writing a paper they will ask you: why this data is taken normal? Either you establish the data was normally distributed, if you do not want to establish I think it is reasonably safe that you assume the data to be log normally distributed.

As shown in figure 3 the particle size categories are altered to produce equidistance range when plotted on the logarithmic basis; this bell shaped curve is log normal curve. It may not be perfect; it is shown for some data. The entire curve when you have this kind of distribution it can just be defined and by the two variables: mean and the variance. You all know about that; so you can find out about the mean and the variance and normally what is written. I want to describe the whole data setup. I will simply write.... Suppose this is not normal distribution for example;

enough for me to describe the whole data set (Refer Slide Time: 15:04 min). You can say log normally distributed with mew and the variance - sigma square; some people prefer because the log normal or geometric mean some people prefer to put zee here; enough to describe the entire data set.

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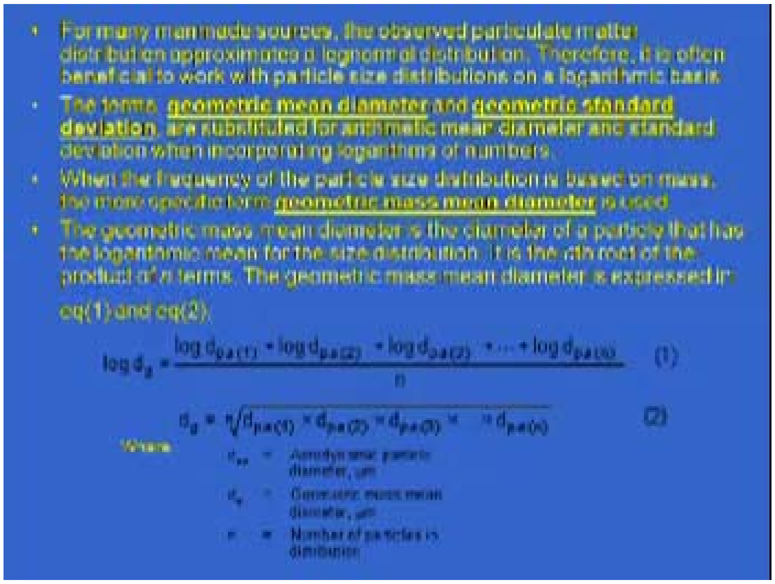

- For many man made sources, the observed particulate matter distribution approximates a lognormal distribution. Therefore, it is often beneficial to work with particle size distributions on a logarithmic basis.
- The terms, **geometric mean diameter** and **geometric standard deviation**, are substituted for arithmetic mean diameter and standard deviation when incorporating logarithms of numbers.
- When the frequency of the particle size distribution is based on mass, the more specific term **geometric mass mean diameter** is used.
- The geometric mass mean diameter is the diameter of a particle that has the logarithmic mean for the size distribution. It is the *n*th root of the product of *n* terms. The geometric mass mean diameter is expressed in eq(1) and eq(2).

$$\log d_g = \frac{\log d_{pa(1)} + \log d_{pa(2)} + \log d_{pa(3)} + \dots + \log d_{pa(n)}}{n} \qquad (1)$$

$$d_g = \sqrt[n]{d_{pa(1)} \times d_{pa(2)} \times d_{pa(3)} \times \dots \times d_{pa(n)}} \qquad (2)$$

Where

d_{pa} = Aerodynamic particle diameter, µm

d_g = Geometric mass mean diameter, µm

n = Number of particles in distribution

How to find out the mean and variance? All this you know, but the other ways to find out sometimes we use. We will quickly define those terminologies because we might use it sometimes when we are talking about the control technology. The geometric mean diameters, the geometric standard diameters, are substituted for arithmetic mean diameter and the standard deviation when incorporating the logarithms of the number.

You can find out.... take the log of each of the particles and then take the simple arithmetic average, but that what it is giving you is the log dg; what I am interested is in the geometric mean. That is what is you get the geometric. This you can simply you can come from here to here. The interesting thing which I want to show you is suppose, it is an observation which are little widely distributed – 3, 5, 9 and you find out the arithmetic mean. I do not what is the arithmetic mean, but if you take the logarithmic mean or geometric mean – what difference do you expect in these two? They should be somewhat similar, of course, because they are both trying to measure the same thing, but you will see here the impact of the larger values is kind of suppressed. That sometimes is better than using it because if you have the data distribution you expect some numbers to be more on this side and then you see it is on this side (Refer Slide Time: 17:23 min). While explaining the things you may try to get more accurate number; the geometric mean is better than the normal arithmetic mean.

This is another thing which we sometimes want to define, which I am not writing here, is the coefficient of the variation. This is your standard deviation divided by mean. A very simple thing, but very useful thing. Why useful? As you see here the sigma gives you the variability in the data sigma gives you the variability in the data and sigma - what units it will have? It will have the same unit as x. Suppose, I am comparing the variability like let us say we are just drifting that is why we talk about water pollution. I am comparing the variability in terms of the BOD and COD or let us say we are comparing what should we say, you are comparing let us say between BOD and PH. Measurement of BOD is in milligrams per litre and that can vary from whatever – 2 to 2000 and PH will vary in their range and the units are different. You want to say about the data that well which one is more distributed; the more distribution you have the less confidence in the measurement because you do not know whether this is this or that. What you can do is that you for any data you can find the coefficient of the variation; the coefficient of variation becomes dimensionless and then you can compare anything versus anything versus anything.

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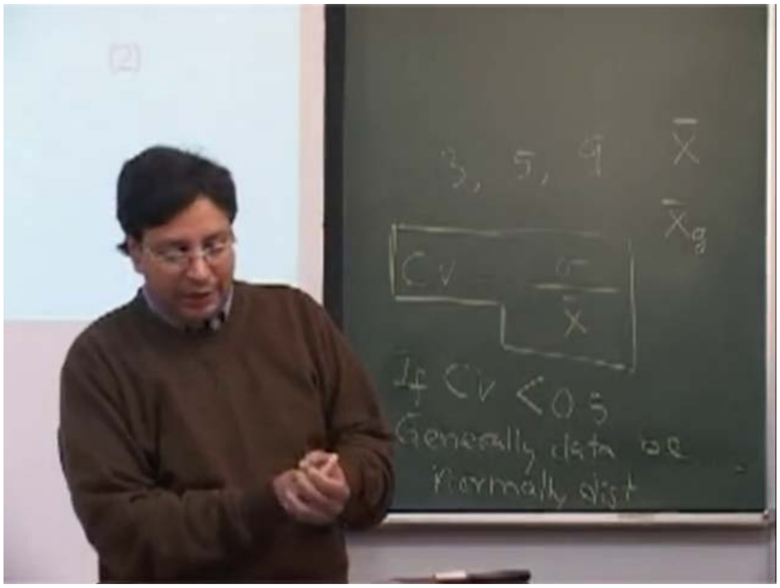

Another little tip it is not it is more like thumb rule or more by experience it has come you can also try this one generally. If is less than 0.5, you would expect data to be normally distributed, generally normally distributed. Sometimes, we also need to find out the mean and variance - sometimes on purpose we find out through graphical method rather than using on your calculators. What you do is use the graphical means then I think I will probably have the slide here. Let us do the example where you want to find out the mean and standard deviation. I will tell you under some particular situation we can only use graphical methods and you cannot use a calculator unless you want to write the programme for something. Understand because this is what we will we encounter this situation many times and we know we should know the basis.

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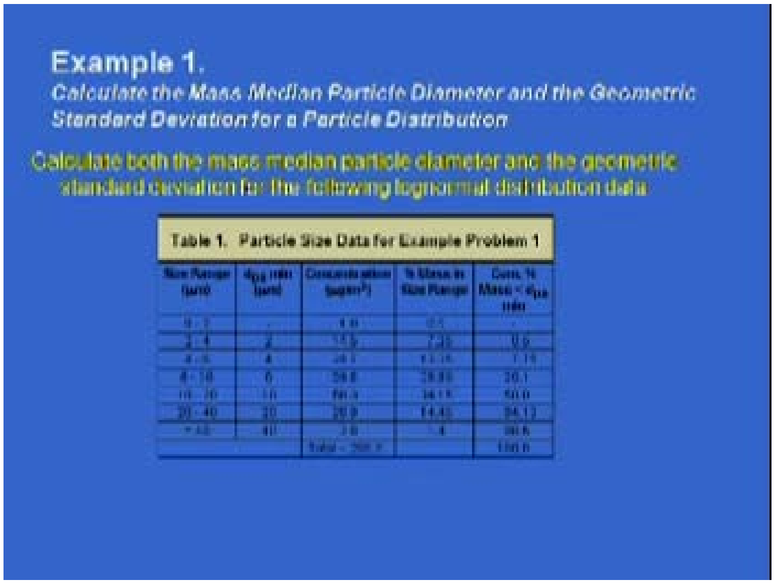

Example 1.

Calculate the Mass Median Particle Diameter and the Geometric Standard Deviation for a Particle Distribution

Calculate both the mass median particle diameter and the geometric standard deviation for the following lognormal distribution data

Table 1. Particle Size Data for Example Problem 1

Size Range (μm)	d_{pa} min (μm)	Concentration (μg/m³)	% Mass in Size Range	Cum. % Mass < d_{pa} min
0 - 2	-	[illegible]	[illegible]	-
2 - 4	2	[illegible]	[illegible]	[illegible]
4 - 6	4	[illegible]	[illegible]	[illegible]
6 - 10	6	[illegible]	[illegible]	20.1
10 - 20	10	[illegible]	[illegible]	50.0
20 - 40	20	[illegible]	[illegible]	[illegible]
> 40	40	[illegible]	[illegible]	[illegible]
		Total = [illegible]		100.0

Example 1 is that we have to calculate the mass median particle diameter and the geometric standard deviation for a particle set distribution which is given here. You have the size range micron metre is 0 to 2, 2 to 4, 4 to 6, 6 to 10 and this is the aerodynamic diameter which is at the minimum 1. Normally we plot the things based on at this minimum level. What was the mass concentration or the mass value or concentration does not matter.

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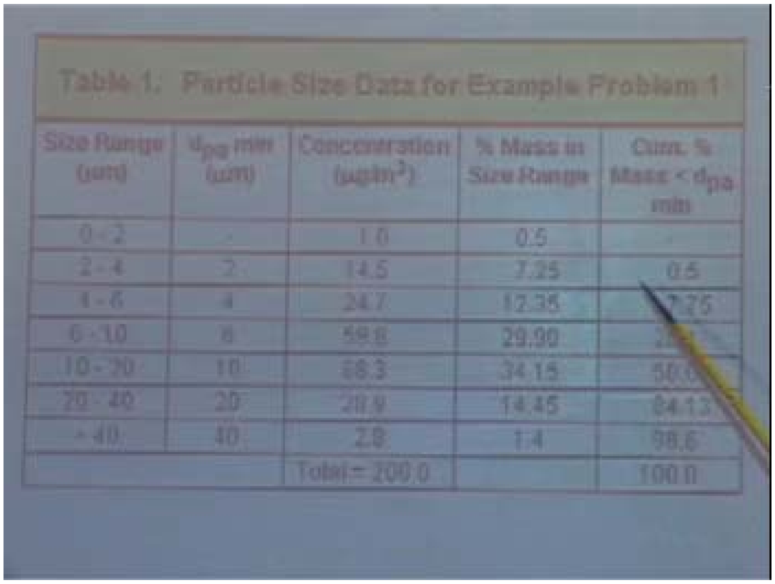

Table 1. Particle Size Data for Example Problem 1

Size Range (µm)	d_{pa} min (µm)	Concentration (µg/m^3)	% Mass in Size Range	Cum. % Mass < d_{pa} min
0 - 2	-	1.0	0.5	-
2 - 4	2	14.5	7.25	0.5
4 - 6	4	24.7	12.35	7.75
6 - 10	6	59.8	29.90	[illegible]
10 - 20	10	68.3	34.15	50.0
20 - 40	20	28.9	14.45	84.15
> 40	40	2.8	1.4	98.6
		Total = 200.0		100.0

Concentration of the particle in the range was from 0 to 2 was 1 micron per metre cube in the first 2.14, 24.7, 59.8 and this and this and this. It can reduce also. No what you want to do is percent the mass size in the range. What have you done here? Now you are looking at the mass. Ho will you get this number? Simply by dividing by 2, in that range. You want to plot the cumulative thing; so you can find out the cumulative here is 0.5; cumulative here is 0.5 plus 7.75 plus 5, 12.35 [ ] is this thing. I finally want to plot is this versus this (Refer Slide Time: 22:45 min) and it will become a straight line provided the data is distributed.

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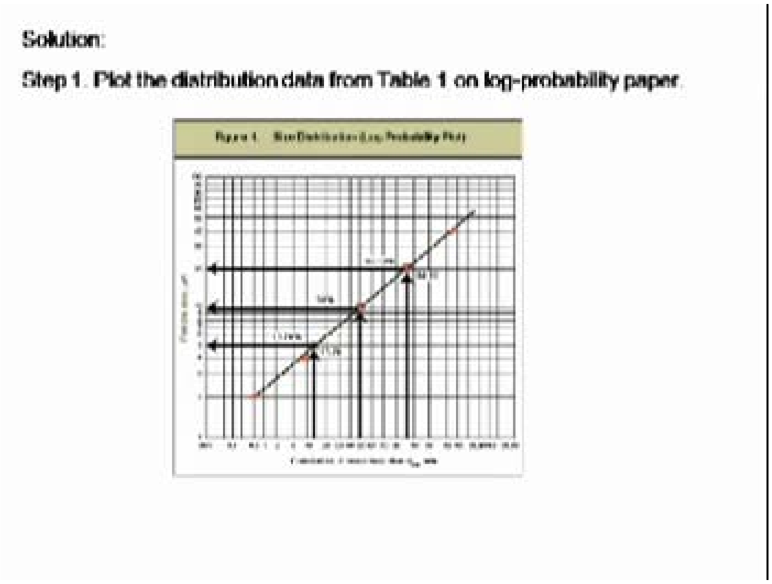

Solution:

Step 1. Plot the distribution data from Table 1 on log-probability paper.

We wanted to find out the geometric mean and the geometric standard deviation. So what I would do is the particle size is plotted on this side on this one what's we are plotting micron metre but on the logarithmic scale.

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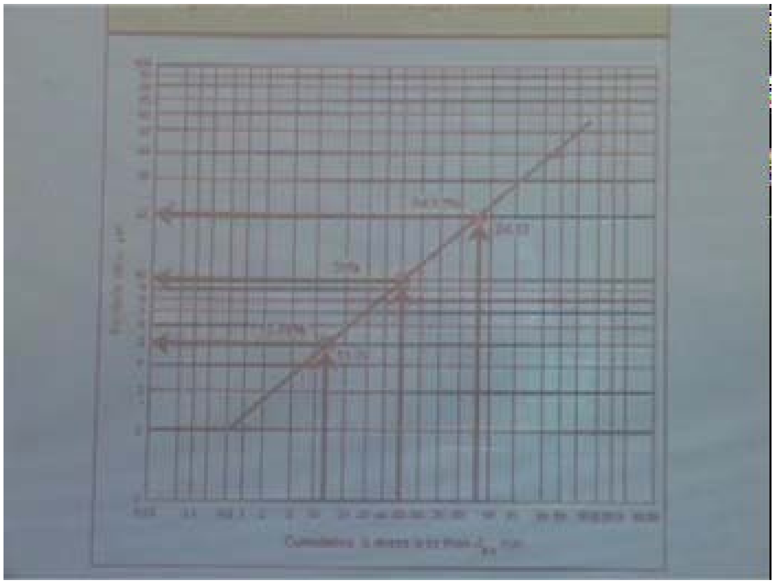

The cumulative mass fraction that also is on the log scale. When you provide both the things on the log scale it becomes a straight line. Now, what you can do is that once you have plotted this, for example, if you recall whatever the range the lowest range was 2; corresponding to 2 what was the mass concentration? 0.5. We went to the range which was like 4; about 4 it was something like 12 point something. You go from here 4 and then something like... well this is a point (Refer Slide Time: 23:56 min). What was that? 12.5; no 7.5; so you will get 7 point something from here. At the 50 percent - D 50 - where the 50 percent of the mass is there and that will be your geometric mean diameter you can find out. This will be the right particle size 50 10 micron is the geometric mean and then if you go 15.78 and 84.13 you will get the value of standard deviation. You know how to find out standard deviation? What was that? Let me also recall here.

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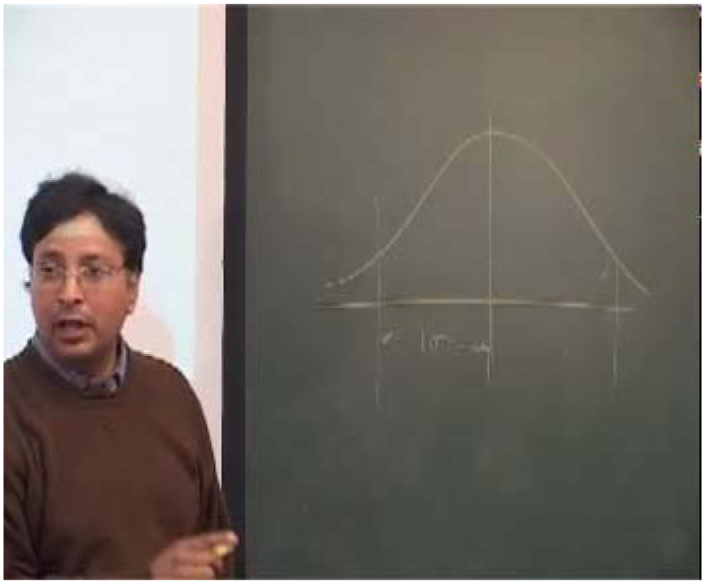

Am I plotting the cumulative? This is not cumulative this is simply frequency block. So, let go on to this straight away. This area - how much is this area? Any one remembers? 60 something? 68 percent. So this will be like 50 and then this will become how much? 15.78. So this can we find out or can we not find out from here? 15 point something. So a simple thing. An important thing is we should make it a habit; we should make it as a practicing engineer, you all time, every time we need to do this. It is like all time you are solving huge equations and things like that. Most of the time you will probably will deal with this thing. So you can find out the standard deviation.

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$$\sigma_g = \frac{d_{50}}{d_{15.78}} \quad (3)$$

$$\sigma_g = \frac{d_{84.13}}{d_{50}} \quad (4)$$

Where

σ_g = Geometric standard deviation of particle mass distribution

d_{50} = Mass median particle diameter, µm

$d_{15.78}$ = Diameter of particle that is equal to or less than 15.78% of the mass of particles present, µm

$d_{84.13}$ = Diameter of particle that is equal to or less than 84.13% of the mass of particles present, µm

How do we find the value of standard deviation? See here, now you can find out the geometric standard deviation. Take the value of D 50 divided by this. Why division? Why would this be? Because, they are logarithmic terms. Whatever observations we are getting the logarithmic value is you divide this by either it does not matter D 50 into D 50 by 7 8 or D 84.3 by D 50 and you will get the geometric standard deviation of the particles of mass distribution. This is your mean and these are, of course, are corresponding to your 15.78 and 84.13.

The other thing that I wanted to tell you was...let me think. Any measurements that you have and you are plotting a cumulative thing.

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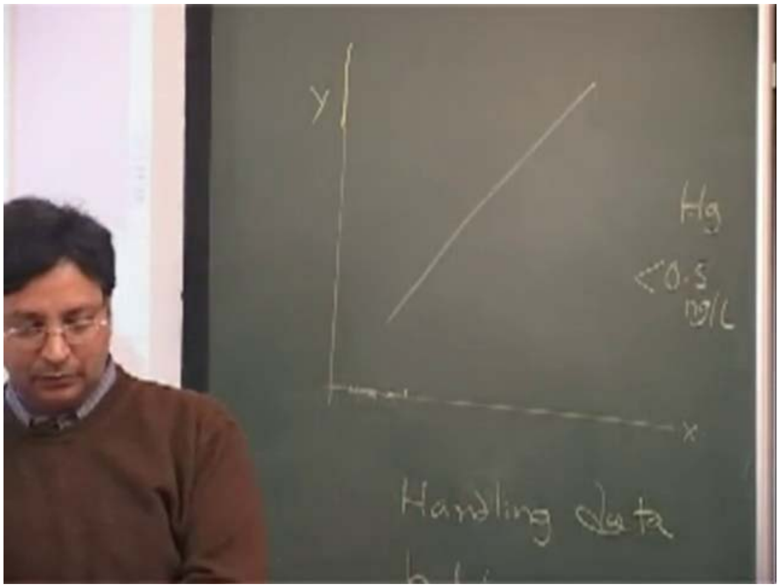

This is the simplest thing I am telling you there are more complicated thing. Handling the data below deduction limit as an environmental people and as environmental engineer is very challenging that you will do some measurements and some data are below deduction limit. You cannot ignore those numbers because that is the information although it may be incomplete information. Suppose you are doing some measurement. Let me say suppose you are measuring, let us say, you are measuring mercury for example and your instrument capability and things like that. Your minimum deduction limit is 0.5 nanogram per litre. Some of the observations are about this; some of the observations are higher. Then how will you utilise this information as well? That becomes tricky. So in that case what you do is you plot the data. Plot the data as the way we have seen it and of course in this range, you cannot plot the data.

You are measuring x and y because something you are measuring and some response. So what happens? x is generally easily measurable when you are plotting x and y; y is the response. Suppose you could measure this (Refer Slide Time: 28:53 min), for this corresponding value for mercury.... Let us say this was your wind speed, for example; wind speed you can measure easily but for that wind speed you measure the mercury and then your instruments are below deduction below deduction. So you can plot the things on the x direction but you do not know what will be the values here (Refer Slide Time: 29:10 min). Because your instruments are less than .5. So, it does not mean that the value is .5; it does not mean the value is 0; it does not mean that the value is .25. We do not really know where this value is, but we do not want to throw this information, nor do we want to use it improperly. Let me tell you a little story about that. Let me see what else is to be covered today before we go to the story.

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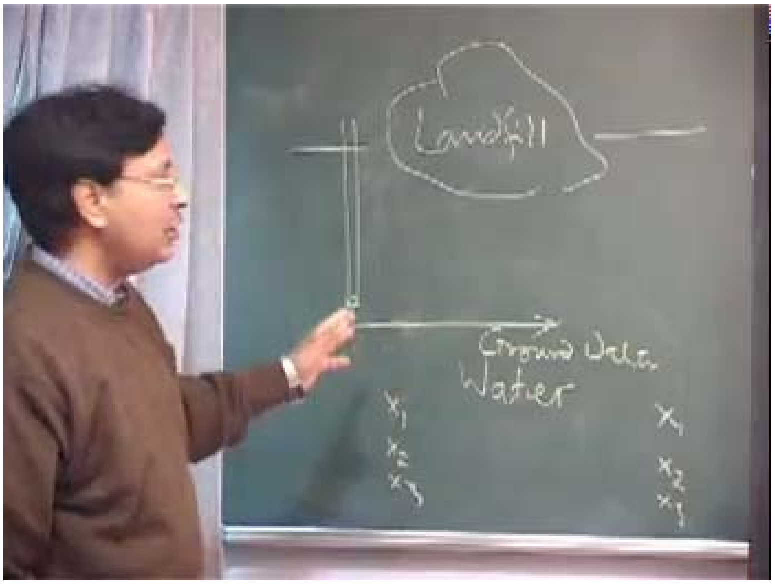

Serious court case in the US. This is the landfill; this is the flow, direction of water; then they have the borewells; they will take some observation because of the [ ] pollution. They are saying that the landfill is polluting the ground water. So they will take some samples in the upstream; and then they will take some samples in the downstream. So they took the measurements; 1, 2, 3; they took measurements here; 1, 2, 3.

Industry which is Landfill company versus the company or the regulatory agency which they want to - they are saying that you are polluting. Then suppose this data were less than 0.5, for example, and now the company said that please take this value as 0; because, they wanted to lower the impact; the regulatory agency said well we will take this to be equal to 0.5. There are more data, I am just cutting this story short. So then it became a problem as to how this value of what x should be taken as - it is anyone's guess. It can be very close to 0.5 or it can be very close to 0 and it makes huge implications you see. This could be closed down; this could be fined; this could be imprisoned; because, they are polluting et cetera et cetera et cetera and same thing.

This kind of a problem can also come into the forensic measurements like the DNA and things like that; like some problem somewhere in the measurement and things like that; lower than this thing or they have some information but incomplete information.

One of the simplest ways I am telling you how to handle these thing is that whatever the good data points you have, you plot. What ever line you have got, you have go this line (Refer Slide Time: 31:56 min); because you know the data is log normally distributed; then you establish that with good data they are log normally distributed; then what you do is you extend this thing in the same slope, and then for this you can estimate a number. Still, God knows what is the true number, but still it is much scientific way to estimate this missing number or missing data than doing it like half of the lower level plus the higher level or take the higher level. People to their advantage will like to make something; somebody will say please take this equal to 0.5. Somebody will say or you should take 0 or somebody says a little science you please take 0.25. None of them are correct, but still there is still many complicated statistical ways are there to handle these but this is the simple thing. You could measure the x, but the y response you did not get through your machine or your equipment what you had, but this is the rest of the data were good, provided you cannot say all the data were below deduction and then you could still improve on that; you cannot. So with this thing, because we know, if it is following some kind of distribution it will continue to follow in all likelihood the same kind of distribution.

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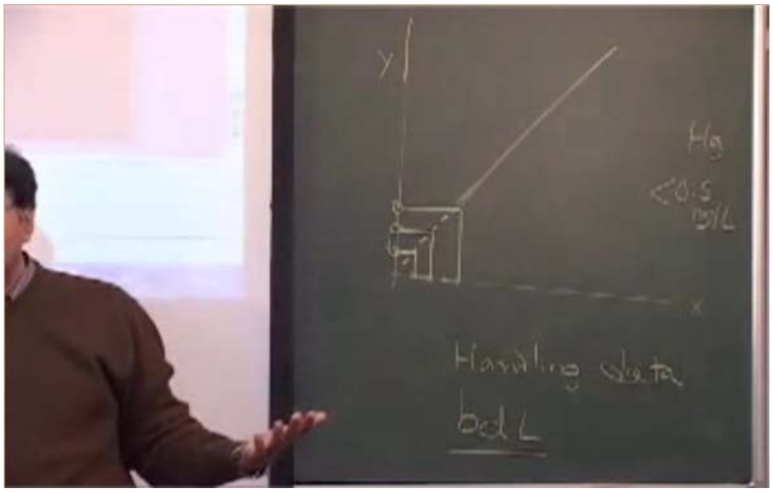

For this you go here find the response y_1 y_2 for this data below deduction; then you use these numbers to find out the overall range mean and standard deviation, whatever it may be.

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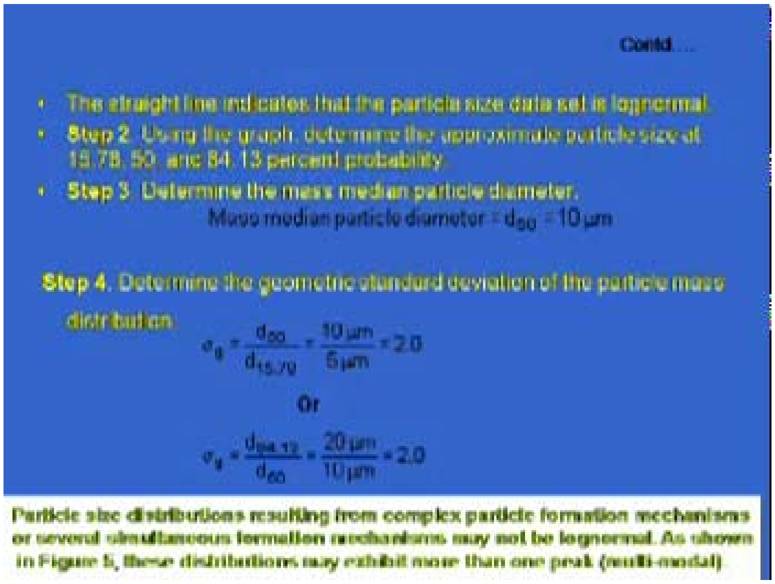

Contd…

- The straight line indicates that the particle size data set is lognormal.
- **Step 2**. Using the graph, determine the approximate particle size at 15.78, 50, and 84.13 percent probability.
- **Step 3**. Determine the mass median particle diameter.

Mass median particle diameter = d_{50} = 10 μm

Step 4. Determine the geometric standard deviation of the particle mass distribution.

$$\sigma_g = \frac{d_{50}}{d_{15.78}} = \frac{10\ \mu m}{5\ \mu m} = 2.0$$

Or

$$\sigma_g = \frac{d_{84.13}}{d_{50}} = \frac{20\ \mu m}{10\ \mu m} = 2.0$$

Particle size distributions resulting from complex particle formation mechanisms or several simultaneous formation mechanisms may not be lognormal. As shown in Figure 5, these distributions may exhibit more than one peak (multi-modal).

It is the same thing what we did and then you go the same graph, you go with this ratio of d 15.2 15.78. It will be more or less very close to this, provided that your distribution was bell shaped and normal distribution.

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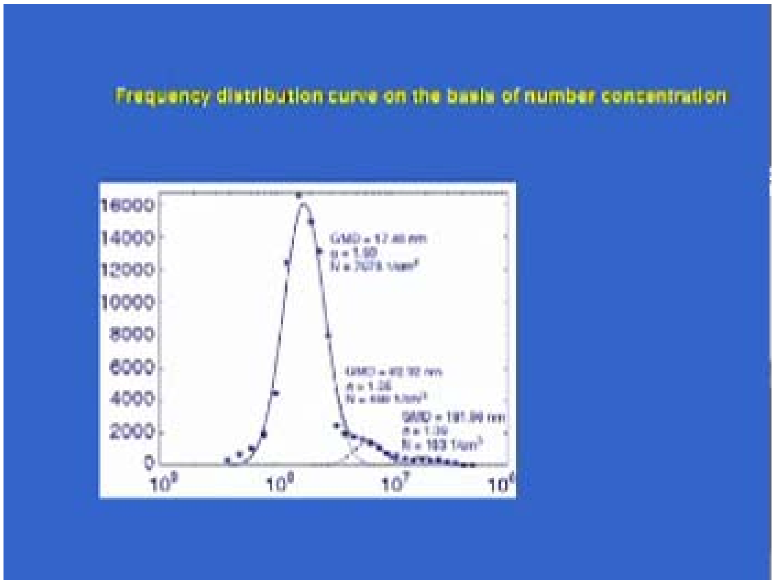

Frequency distribution curve on the basis of number concentration

We will leave that graph for the moment. Sometimes you will find that some of the graphs are plotted and then you should approximately understand that why they shape the way it is. Here what we are plotting here? The number concentration. Here what are the units? Probably at the back you cannot see, they are really in the nanometres. When it comes to the number particles on the higher sides, like this will be - what is the size of this particle? 10 to the power of 6 nanometre will be what? 1 mm or something or you reduce this one; you can find out. This is 10 to the power minus 6 nano meter; you can say 10 to the power 3; this is micrometre - can we say that? (Refer Slide Time: 34:48 min). You can find that out now, but what you see here the smaller particles, what you see the particles are small, they are more in number.

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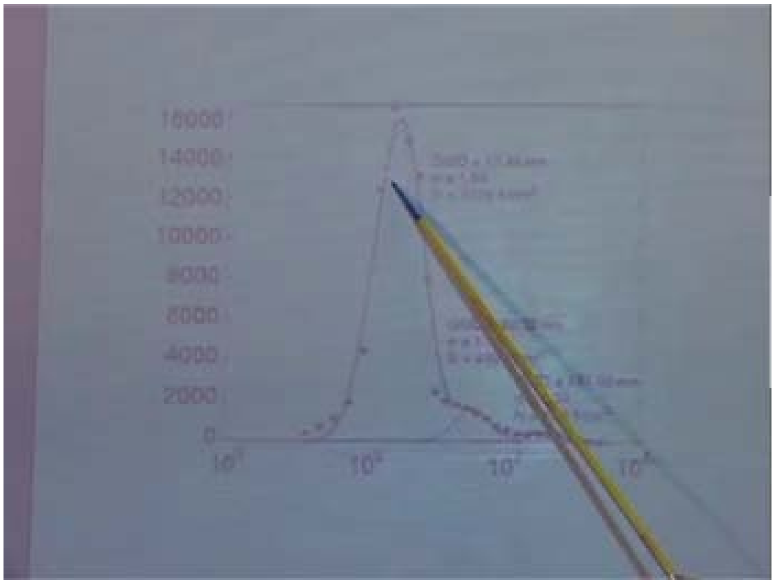

If you have to see the graph then whether you are talking about the mass or the number, and if you look at the mass, the distribution is entirely different.

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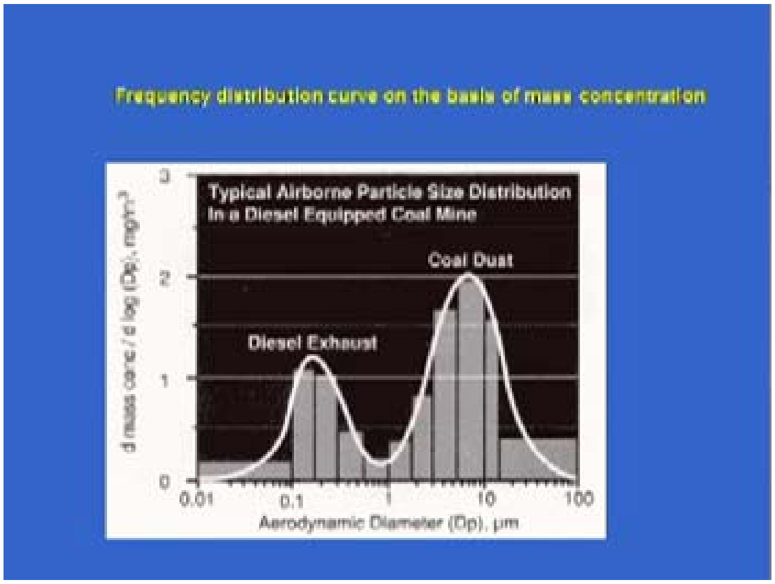

Frequency distribution curve on the basis of mass concentration

More mass comes on the larger size particles and the numbers are somewhere here; large number almost insignificant number which is there. Depending on what you are using, you are using it for numbers because these are some of the medical doctors would prefer number concentration rather than the mass concentration, but in environmental air pollution we mostly need the mass concentrations. Here you see change in the mass with respect to the change in the diameter on the logarithmic scale that is plotted here and typically we get this kind of distribution. You get bimodal distribution; one are the sources or the particles which are generated more from the mechanical operations. These are the operations come out more because of some of the process and those processes happens in the atmosphere.

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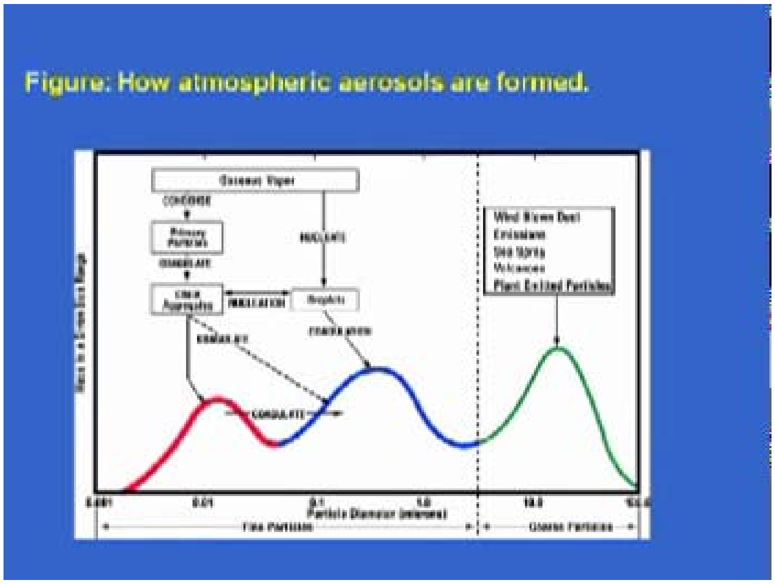

Figure: How atmospheric aerosols are formed.

Here are the windblown dust emissions, seas spray, volcanoes, and the particles - more of the grinding kind of thing - soil dust and things like that. We have the large particle range here; whereas, when there are finer particles, they are formed rather than they are you can create them really I mean through the mechanical devices. You have the gaseous vapour. You have a very high vapour; lots of the concentration - super saturated. Obviously, condensation will occur and then it will little make the primary particles. They can very small particles, very small particles; they can come and they can coagulate and make slightly larger particles, but the other thing which happens very quickly, if you have the other particles present in the system they can act as a condensation nuclei; the vapour can condense on them and then as a result even if the saturation is not is not super saturated, you can see the droplets being formed.

That is how it happens in the cloud. It is not hugely super saturated, but you have the little seeds in there; as a result the droplet will be formed; then it can grow in the size little bigger size because you already have a parent particle on which it will settle, but in the process the particles in the atmosphere we call it ageing.

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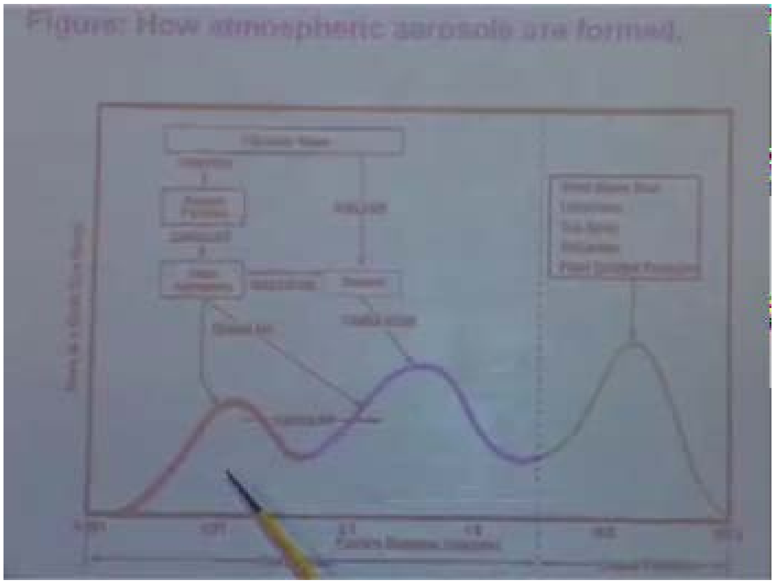

These particles like even if they are smaller, they come and then they agglomerate, they coagulate and then they tend to come more on to this side with time. If you are very close to a source, let us say close to a power plant emitting at the ground level, you might find lot of distribution like this. A few kilometres from there and then you can find this thing. Then this, of course, is the other mode which will be there always (Refer Slide Time: 38:04 min).

What will happen? These particles can coagulate, but these particles do not coagulate (Refer Slide Time: 38:15 min). Whatever their distribution you get in this... What will happen when you get away from the source? This trimodal distribution, as you see, this eventually becomes something like this (Refer Slide Time: 38:39 min). Therefore, all our studies in air pollution, what we do generally, we are dealing in the fine mode that is up to something it will come close to 2.5. Distinct things you will get in the atmosphere. Therefore, all the things we are talking about, all the standards that we have been talking about, all the people we have been talking about, is that about particles with PM 10. Why PM 10? Although you will get a size distribution like this, beyond that, the effect of that air pollution effects are not so significant; because, these are the mostly stopped at the nasal cavities and things like that. PM 10 can go to the upper part of the respiration system, but these particles, these become very dangerous. So what you see here is all the time people ask you - why 2.5? What is so special about 2.5? Where has this 2.5 number come?

My idea is you should always know the simple basics; equations anyone can solve. You should know the physics and you see here why this particle with 0.001 ultra fine. Eventually as you move away from the source, it will become something like this and almost dying down here and then it is picking up here. It becomes very important to study the fine particles of the origin which is largely comes from the gaseous vapour or from the processes the combustion process; in fact these things are not so harmful at all. We have been living in the northern part of the country; tropic condition dust storm is all there for us; that is how we live. We go to Rajasthan, in the month of March or April, the dust is everywhere; no one coughs and no one gets kind of worried about it. Look at these particles; they come from the diesel and other sources they are the matter of serious concern. That is how by the trimodal distribution becomes, eventually becomes, bimodal distribution and that is how the issue of PM 2.5 comes in. That is because that is the two modes and then that is why we sometimes use the cascade impactor to differentiate between 2.25 and 0.25 and 10.

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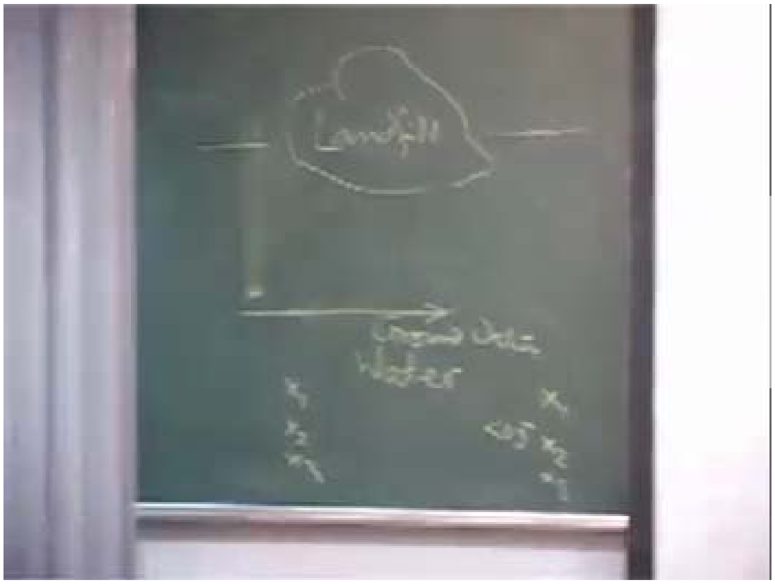

Something similar kind of graph as you go away from it.

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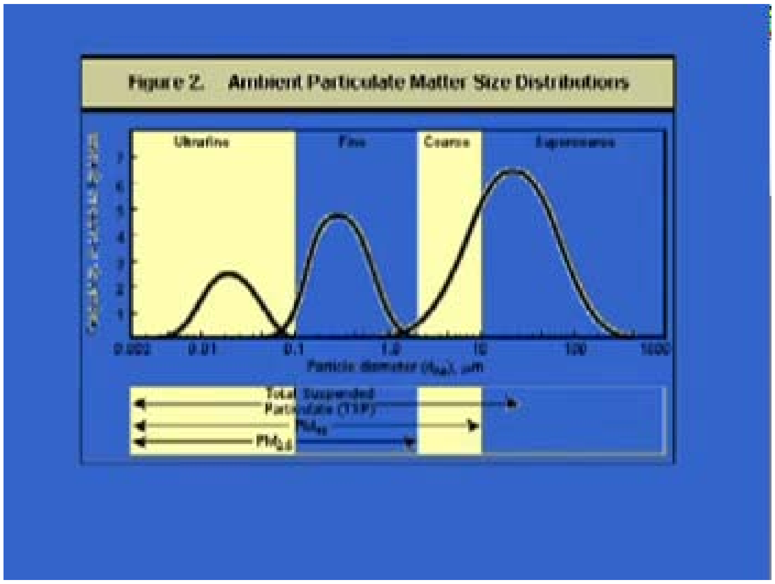

Figure 2. Ambient Particulate Matter Size Distributions

Remember we gave this range as the name of course between PM 2.5 and PM 10; ultrafine and this and that.

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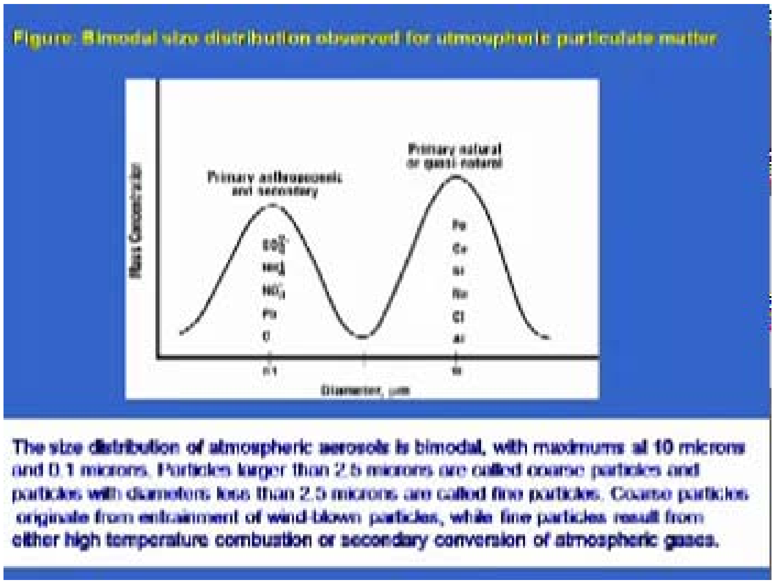

Figure: Bimodal size distribution observed for atmospheric particulate matter

The size distribution of atmospheric aerosols is bimodal, with maximums at 10 microns and 0.1 microns. Particles larger than 2.5 microns are called coarse particles and particles with diameters less than 2.5 microns are called fine particles. Coarse particles originate from entrainment of wind-blown particles, while fine particles result from either high temperature combustion or secondary conversion of atmospheric gases.

If you look at the characteristics this will be all in the like the sulphate, the nitrates; these are mostly the sulphates, nitrates, ammonium is not from the soil. They have all been formed in the atmosphere. These are the typical conclusions: you get lots of silicon in the soil; calcium is there;

aluminium must be there; ammonia is there. They are more like the larger particles: soil, dust and that is there, but these are the primary and the secondary particles. They are the quasi natural kind of things. So when you do the study of this chemical composition, you can almost say the way the particles have come from. Suppose you are getting this level, these levels are much higher it may mean the particles are mostly secondary origin and their finer fraction is large (Refer Slide Time: 42:03 min).

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Particle Formation

The range of particle sizes formed in a process is largely dependent on the types of particle formation mechanisms present. The general size range of particles can be estimated by simply recognizing which particle formation mechanisms are most important in the process being evaluated. The most important particle formation mechanisms in air pollution sources include the following:

- Physical attrition/mechanical dispersion
- Combustion particle burnout
- Homogeneous and heterogeneous nucleation
- Droplet evaporation

This is very important and then we will finish this one. How are the particles formed? Especially these smaller particles? The larger particles, we know, one is set the way they are formed is the physical attrition or mechanical dispersion. Another is from the combustion particle burnout and another is the homogenous and heterogeneous nucleation, and droplet evaporation. You will understand because fortunately we have good pictures coming up for you.

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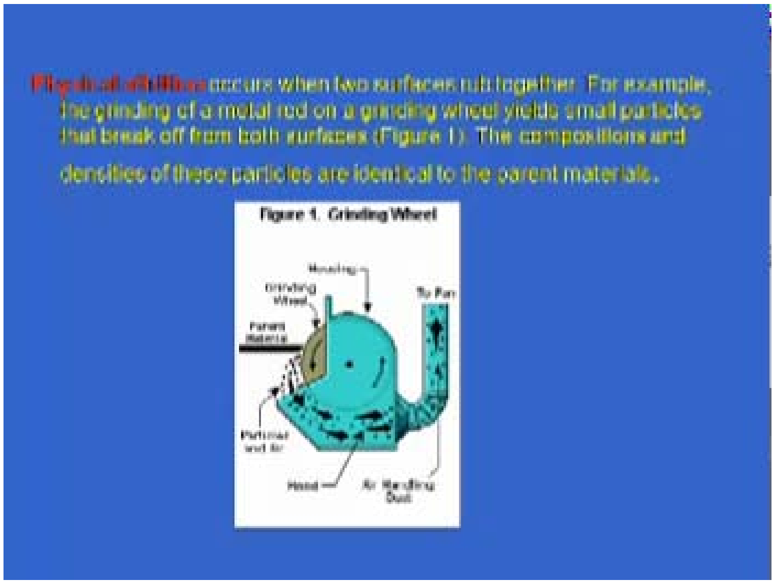

Physical attrition occurs when two surfaces rub together. For example, the grinding of a metal rod on a grinding wheel yields small particles that break off from both surfaces (Figure 1). The compositions and densities of these particles are identical to the parent materials.

Figure 1. Grinding Wheel

Physical attrition - we have the large particles that can be formed in the industrial processes. This is the grinding machine; basically grinding wheel; things are being grinded; very common thing, especially, any old processing to begin with the grinding is done. You will see the little particles falling off and then you are collecting with the fan and these particles will be the large in the size if you do not mention here it will be shown in a moment. It occurs when the two surfaces are rubbed and you'll see small particles that break off from most surfaces. The compositions and the density of these particles are identical to these particles. That will not change. This is one way.

The second thing is second way the particles are formed is they are they are more kind of crushers are there but they are not being shown. Combustion particle burnout - this is important to understand: why the fly-ash is generally much smaller than the coal that we are firing? Because the particle is completely burned out. As combustion processes, fuel particles which will be larger which started as 10 to thousand micron particle from the coal mill are reduced to ash and the charred particles that are primarily in the range 1 to 100 micron range. This mechanism for particle formation can be termed as combust particle burn out.

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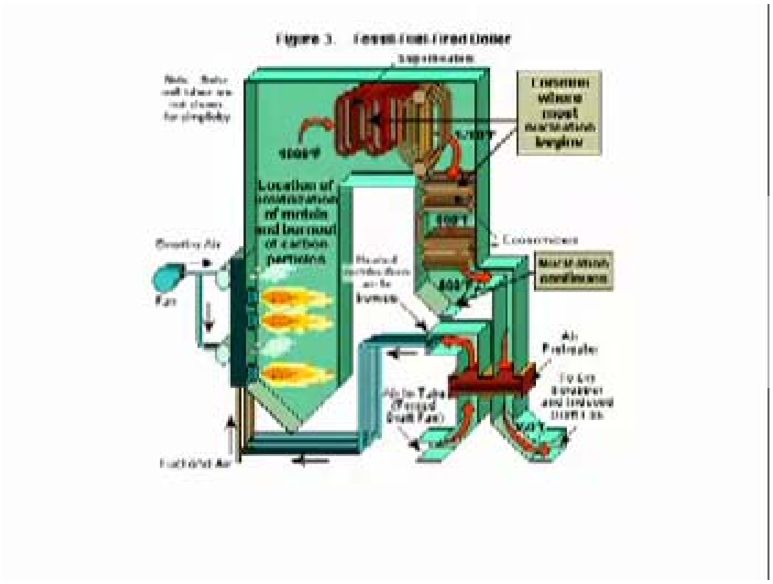

When the combustion particle burn out and the nucleation occurs in the fossil fuel fired boiler - nucleation is discussed little later in this section we have here. We are just talking about the particle burn out and everything together here. So once we are firing the particles here, it can be here; this is the air which you are firing; the particles may be much larger here. Immediately the organic matter or some of the metals, for example mercury - quickly evaporates; some metals will not evaporate. In fact, lead also, to a large extent will evaporate. The cooling is there and this is the location where most nucleation occurs. The moment when the temperatures drop, the nucleation can occur right here. Largely, it is talking about the nucleation which can occur right inside the process (Refer Slide Time: 45:13 min). This is because you need certain temperature; with that temperature some of the burnout is not complete. The vapours will continue to go up and the vapour, now there is no opportunity for the vapour to burn out. So the vapours escape. Then through the nucleation they can become particles.

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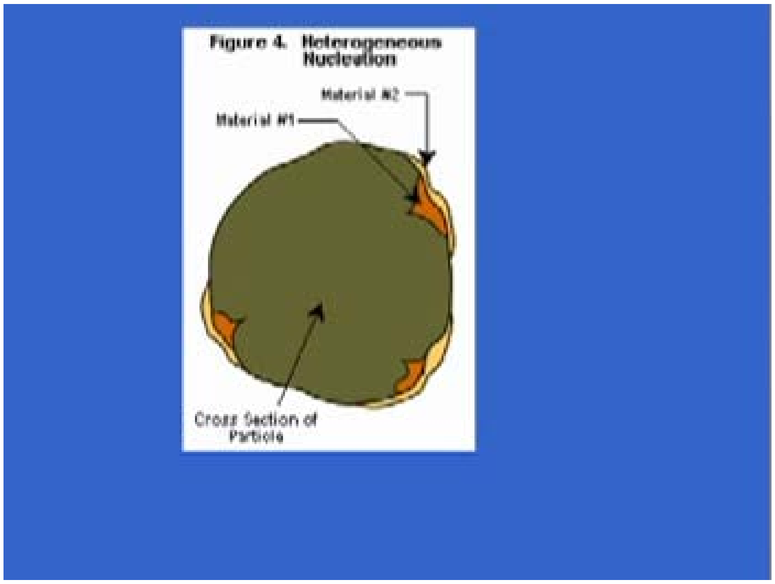

Figure 4. Heterogeneous Nucleation

This is nucleation. You should understand; maybe, we will talk again in the next class. There are two kinds of nucleation: one is heterogeneous nucleation and one is homogeneous nucleation. For heterogeneous nucleation, you need some already some parent particle on which the nucleation of your vapours, that is, your material one should occur. If you do not have the metal material two, then the homogeneous nucleation can occur. For homogeneous nucleation to occur the super saturation level has to be very high; otherwise, that will not happen.

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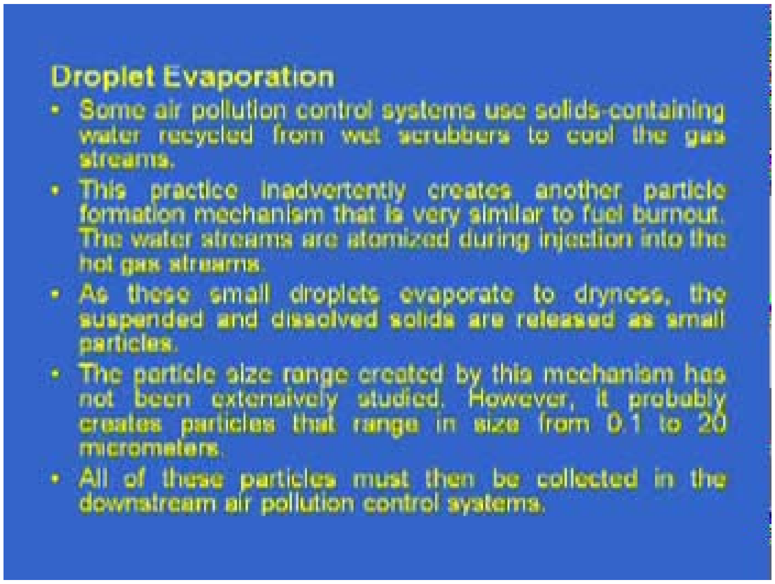

Droplet Evaporation

- Some air pollution control systems use solids-containing water recycled from wet scrubbers to cool the gas streams.
- This practice inadvertently creates another particle formation mechanism that is very similar to fuel burnout. The water streams are atomized during injection into the hot gas streams.
- As these small droplets evaporate to dryness, the suspended and dissolved solids are released as small particles.
- The particle size range created by this mechanism has not been extensively studied. However, it probably creates particles that range in size from 0.1 to 20 micrometers.
- All of these particles must then be collected in the downstream air pollution control systems.

The another thing maybe some of the coastal area, the natural resources, also find out the droplet evaporation because you see somehow the water droplets may escape from the sea or some evaporation. Then the moisture it evaporates and leaving beside its dissolves solids in the atmosphere which will be very fine particles. You will be surprised – we have a lot pf scrubbing systems for treating the ...

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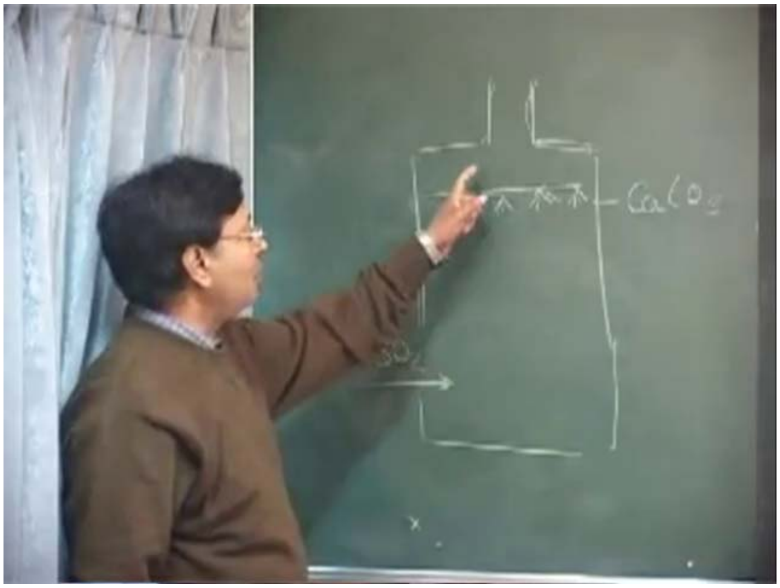

Suppose I am entering SO_2 here. I am using spraying something that can dissolve the SO_2, maybe a slurry of calcium carbonate. After this thing, there will be few the missed particles that will emit out; at the source, this is the source, as they emit out from here, you can see some of the particles coming, which maybe sometimes looks like water or something like that, but eventually the water evaporates and it leaves lots of particles in the atmosphere, which are dissolved in the water spray.

That is another source we will discuss a little bit more in details of this thing in the next class. You can see the mechanisms: the burn out is a different thing; nucleation is a different thing; [ ] is a different thing; and ordinary mechanical crusher is a different thing. They will all give different particle size. If some particles are formed through a chemical reaction that will always be very fine.

We will stop this one here.