Particle Characterization

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Module No. # 03

Lecture No. # 06

Morphological Characterization:

Static vs dynamic methods of size analysis

Welcome to the sixth lecture on a particle characterization course. Just to recap, what we have learnt so far in the first lecture - we talked about why it is important to study particle characteristics. In the second lecture, we listed various characteristics of particles and briefly discussed ways in which the characterization can be accomplished. And then in the next 3 lectures we started a discussion of specific properties or characteristic of particles; starting with morphological characteristics and we have so far, discussed various ways in which the shape of a particle can be analyzed.

Now, if you recall from our second lecture, I mentioned that the two most distinguishing this physical characteristics of a particle are shape and size. So, logically we should discuss size characterization of particles. Next, now, to large extent size and shape are inseparable, when we define a particle by a size; we are implicitly defining its shape also. For example, if you say that the diameter of a particle is so much, it certainly describes the size of the particle, but it is also describing the shape, as being spherical in nature or if you define it by, let us say, one long dimension and one short dimension, it gives us a an indication of the size of the particle, but it also tells us that the particle is roughly ellipsoidal in shape.

And that is why the two shape and size characterization must really be studied together; so to speak. Now, when we talk about size, it is important to realize that what we see as size, it is again not an absolute measure size is always relative to something; for example, you can even you look at an object. Let us say like this bottle and if I were to ask you to tell me what is the size, you will tell me a size that is based on your visual observation of the object.

Now is that actual size, I mean how you even define absolute size, As a particle gets smaller and smaller. You cannot rely upon simple naked eye observation to assess size and you start using various instruments to do that. As you start doing that the relative nature of particle size becomes even more important to take into account; typically as particles get finer and finer the way that size analyses is done is related to their functionality. For example, if you are dealing with a particle and you want to know at what rate it will settle in a liquid and you want to define a size that corresponds to its settling characteristic, then you will actually define something called an equivalent settling diameter, which is defined as the diameter of a spherical particle that settles at the same velocity as the particle under consideration.

So, the size that you are defining here is not really the absolute size of the particle, but rather a size that references a spherical particle with settles at the same velocity.

Another example, of such a relative measure of velocity is an aerodynamic diameter. Aerodynamic diameter of a particle, refers to again the size of a spherical particle which experiences the same aerodynamic drag, as the particle under question. So, the same particle can essentially display multiple sizes depending on the nature of the process that it is involved in.

So, for the same particle you could define an aerodynamic size, you could define a settling size, you could even define a scattering equivalent size, as particle get finer we will see later, the technique that is most widely applied to do size characterization is based on scattering of incident light.

So, you can think off an equivalent scattering diameter of a particle, as the size of a spherical particle, which scatters light at the same intensity, as the particle under question. So, the point is for each particle you do not really define one absolute size, you define multiple sizes based upon the most relevant functional characteristic. And this multiple city of sizes keeps increasing in magnitude, as particle becomes smaller and smaller, because it becomes increasingly difficult to define and absolute size based upon simple visual inspection.

So, how do we define size of a particle? Actually, some of the definitions that we used during our shape characterization discussion or obviously relevant for size characterization as well, just to take an example - the distance between tangents or

surfaces, that are parallel surfaces that are tangential to the profile of a particle, that we used as a measure of shape, but when you actually think about it, it is also a dimension that is a measure of size or another example would be lengths of intercepts, we talk about Ferret's diameter and Martin's diameter and we took the ratio of the two as an indication of shape, but if you take the actual magnitudes of the Martin's diameter and the Ferret's diameter it actually gives you a indication of the dimension or size of the particle or even some of the ratios that we used as shape comparators, if you look at the definitions of those ratios and you take a numerator and the denominator separately they are actually indications of size.

So, in a way a, shape comparator is a ratio of sizes of two different objects and that is why again the point is that shape assessment and size assessment or in-extractably linked and you really cannot study, one without studying the other.

So, when we talk about size what do we really mean, we talk about nano particles, we talk about micron size particles, we talk about millimeter size particles and much larger particles.

We need to have a little bit of prospective prespective and what this dimensions mean. For example, the smallest particle that a human eye can see is about any idea it is actually 50 microns. And a human eye can see particles that are as small as 50 microns, which is point 0.05 millimeters. However, it cannot resolve particles with better than 100 micron accuracy, now what is the difference resolution refers to the minimum distance of separation between two objects where you can still tell them a part,

In other words, a human eye can only distinguish particles that are 100 microns apart or more, if they are closer than that a human eye cannot even tell that these are two discrete particles, it just basically counts them as 1. Our hair is about 100 microns in diameter; dust that we normally talk about, environmental dust certainly 100 microns and larger, granules, droplets, these are all terms that we usually used to describe particles they are all in that courser fragments and again when we talk about particle science the definition of what is fine and what is coarse will also depend very much on the investigator.

So, something that I might consider to be a fine particle, someone else might consider to be a coarse particle but some conventions have been established. For example, when you talk about nano what is the size range really? Any idea, the range what is the minimum

size in a nano range and what is the maximum size in the nano range? Conventionally 1 to 100 nanometers is considered the nano size range, it does not mean that you know, 0.99 nanometers is not nano it is just a convention that has been established, because so many people got involved in nano technology and to a large extent that a whole term started to get abused. So, the needed to be a clear definition of what is the size range that we really talking about, when we say nano technology.

So, roughly 1 to 100 nanometers is nano technology. So, by definition anything that exceeds 100 nanometers, which is 0.1 microns would be considering the micron size range. In fact the 0.1 micron to 1 micron size range is call the sub-micron size range and size is exceeding 1 micron, all the way up to roughly 100 micron is called the super micron size range. So, the micron size range essentially encompasses both; so from 0.1 microns to 100 microns would be call the micron size range.

So, when people talk about coarse again by conventional definition anything that exceeds 100 microns or 0.1 millimeters would be considered a coarse particle and anything that is 100 microns and finer could be consider a fine particle. So, dust may be considered to be somewhere in the course coarse to find range. Most of the larger dust particles would fall in the coarse regime, similarly droplets tend to be larger than a 100 microns. There are also aggregates and agglomerates that are constantly being encountered in the environment.

Now, what is an aggregate and what is an agglomerate? The idea is the particles are always trying to find each other, that is a tendency for particles to become cohesive in nature. In other words, if you have two particles, especially very fine particles that are separated by a medium. The surface energetics dictate that the particle tries to push the medium out of the way and join together.

Now, when two particles are loosely joined together, they are called agglomerate; whereas if the joining force between the particles is substantial and it requires force to break them a part. Then they are called an aggregate.

Now, when you look at particle size distributions in nature, it is a very rare that you encounter mono dispersed populations. Virtually all the populations that we deal with are poly dispersed. Now, what is the difference between the two? A mono dispersed population essentially is a collection of particles that are characterized by a single size.

Whereas the poly dispersed population has a distribution of sizes, and the concentration or number of particles in each size range will vary depending on the sources of the particles, as well as the processes that these particles undergo in real life.

So, most of the time, we will deal with particle powders or populations that are characterized by a wide range of sizes, which can vary all the way from nano size to the super micron size to even larger sizes. The broader the spectrum of particle sizes that we have to deal with, the more difficult actually the analysis part becomes, because as you look at various methods that are used to do size characterization in various size ranges they vary tremendously. The same method that you can use to measure the size of a ten micron particle, you cannot use to measure the size of a 10 nanometer particle.

Now, there are certain techniques like electron microscopy, which in principle can be use to look at, at least a 10 to the power 5 range in particle size. Simply by adjusting the magnification of the lens. The difficulty though is if you try to use something like a scanning electron microscope to do size characterization, the amount of time and effort and experties involve is mostly an overkill, because what these instruments such as electron microscopes, we are really not designed or intended for doing quantitative sizing of particles. They are qualitative characterization tools and that is a very important distinction to make, because a quantitative tool is one that you want to use virtually on a daily basis and you want to use it on as many samples as possible, in order to establish some process understanding and process control.

So, by that definition quantitative method for particle size characterization, should be something that is easy to use, should not require an operator with advance degree to operate it, should be quick, because you want to turn around samples rapidly, should be inexpensive and it should give you numbers that you can use to compare against a historical data base or against a different process that is being run elsewhere and so on. Whereas a qualitative size characterization tool can be something that can be use offline, you do not do it routinely, you only do it on an as needed basis, it is typically used as more of a confirmatory test you cannot always rely upon these quantitative tools, because they are vary very simplicity also leave some open to doubts, how confident are you that let say, you are using something like a laser light scattering instrument to measure particle size and it gives you number, how sure are you that this number is real.

So, you do have to periodically go back and substantiate your quantitative results with qualitative characterization, but the clear understanding is qualitative characterization tools are always more expensive, analysis is much more time consuming, they always require much more experties expertise, from the operator. And they do provide a lot more insight in to the process, the material or the mechanism compare to simple quantitative tools, but each has its use. And so we need to understand really both types of size characterization techniques and we will try to do that in the next few lecture.

Now, going back to size characterization, there are broadly two ways in which particle size is characterized.

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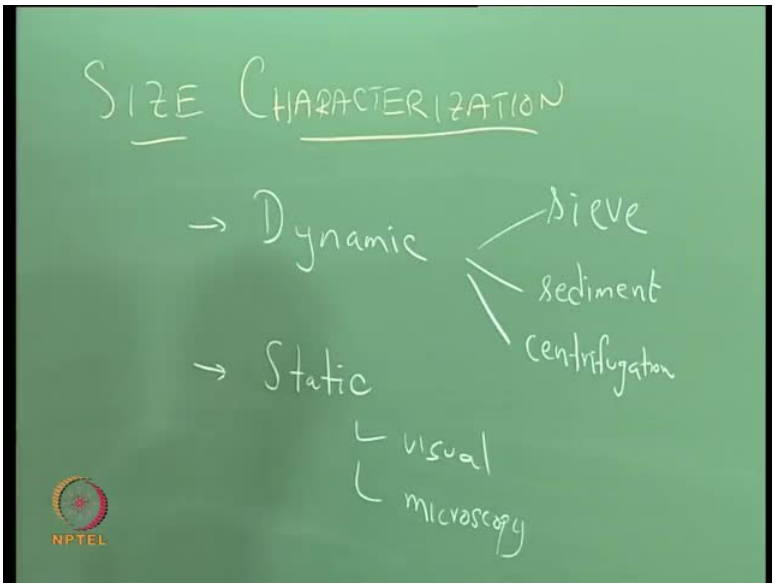

The first technique, is dynamic and the second is static, So, what do we mean by that when you are trying to do characterization of size of either a single particle or a population of particles. You can either, set particles in motion and study that transport characteristic under an applied force and from that you can extract the size information or alternatively, you can actually capture the particle fix it in one place and then use certain analytical tools to observe its size.

So, the first technique is what we call a dynamic method, where the particles are actually in motion and you are studying them, as they are moving and deriving size information from that whereas, the latter method, where you fix the particle in place and analyze it is refer to as a static method.

Now, I am sure, you have all taken mechanical operations; mechanical operations course and you probably recollect some of the techniques that you used for size characterization. In that course, and in that lab, methods like sieving, sedimentation, centrifugal classification. Now, these all fit in a category of what type of technique, dynamic, because in all these methods you are essentially setting the particles in motion and based on their behavior under the applied field or applied force you are assigning a size to them.

So, these dynamic methods are very widely used and they do provide quantitative information, but the clear understanding is the size that you define using dynamic technique is clearly a relative size.

So, for example, if you are doing your dynamic size characterization by sieve analysis or let us say you are doing it by sedimentation or by centrifugation, in each of these cases the force that you use set the particle in motion is very different. So, the size that you measure is also going to be relative to that force. For example, in sieve analysis how do you measure size? You basically take a set of sieves with different mesh sizes and you put the coarsest mesh at the top and then, put the finest mesh at the bottom and you have a collector plate below the finest mesh and then you take this particle powder, whose size distribution you are trying to characterize; put it into the top sieve have some kind of a sieve shaker arrangement, which is designed to give very abrupt but at the same time very reproducible movements to this stack, when you essentially vibrate the whole stack.

So, what happens to the particles that you have put on the top sieve here, the coarsest particle that you have which are coarser than the top most sieve stay at the top most sieve. And then the final ones drop through the mesh openings to the next pan bellow or the next sieve. And so, they just make their way down, until the finest particles make all the way down to finest sieve and finally get collected.

So, in this case, the property of the particle that you are doing for size measurement is what as you are vibrating the particle; you are simply making use of the fact. If the particle diameter is greater than the opening or the mesh size it will stay; if it is smaller it will pass through.

Now, what mechanism is that is that a word for it that is used. It is a kin what we would describe later as interception. So, essentially these holes or these meshes, the openings or

intercepting particles, as we are trying to pass through and if the particle is larger than the mesh opening then it gets caught if it is finer it passes through.

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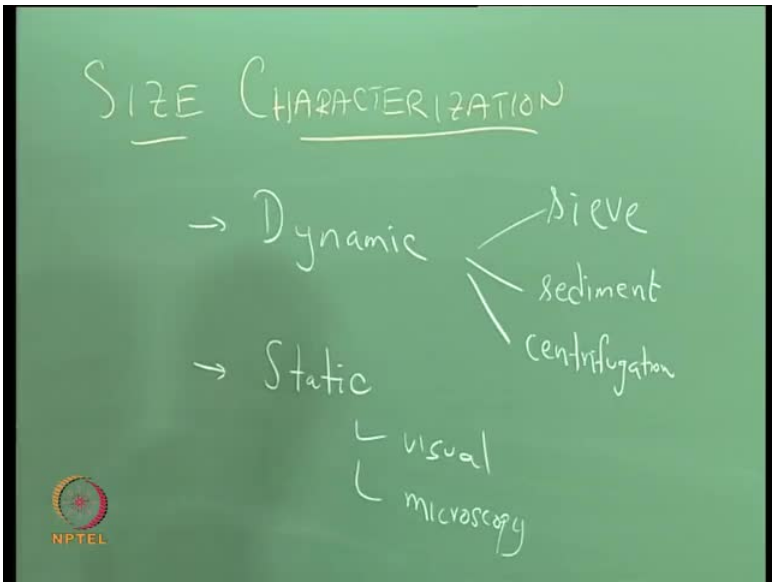

So, sieve analysis is probably, the most widely used technique for doing size characterization, but what are the drawbacks? The smallest size that conventional sieves can separate and size classify or about 40 microns sieves, if the particle size is smaller than 40 microns they will slip through. Now, there are sieves that are called micro sieves, which can take you down to 20 microns,

But once you start going below that there are too many problems, with trying to do this type of sieve analysis. The first thing that will happen is what is known as blinding? Essentially many of the pores or the mesh openings will get clogged by particles that are not able to pass through. So, eventually you will start losing your sieving efficiency. The other thing, that can happen is essentially, some particles will start bypassing and start flowing through.

The third difficulty with sieve analysis is that is very shape dependent. For example, if you have perfectively spherical particles, then no matter in which direction or in which orientation, the particle approaches the sieve. The sieving efficiency will be the same. However, you can imagine that if you have a highly elongated particle, then the probability of whether it is going to get caught in a particular mesh or pass through will

depend all most entirely on, whether it approaches that mesh in a horizontal or length configuration or in the shorter configuration.

So, depending on if it comes like this or like this, it may get caught or not caught. So, the shape distribution, it becomes more of a probabilistic measure and so what that means in a practical senses, you have to do it with the statistically; you have to take multiple samples of the same powder and do repeated sieve analysis. In order to, develop some confidence in the data, because the irregularity in the shape of the particles introduces an element of uncertainty or error in your analysis. So, these are some of the limitations of the sieving method.

Now, how about sedimentation, how does that work? It is basically based on the settling characteristics of a particle. So, the particle will reach a terminal settling velocity, which will be characteristic of the size of the particle, as well as density of the particle. For example, so if you assume that the density is the same, then you can actually separate particles by size based on their settling time and you can then either use the equations. Governing the settling of particles, to calculate the size based on the time taken or you can actually do something like a beaker decantation, where you collect particle that have settled for different periods of time and then do weight measurement or you can even dry the particles and do sieve analysis and other techniques to do the size distribution analysis.

Now, sedimentation is a technique, it is basically wet technique compare to sieving, which is predominantly a dry technique although they are wet sieves that are also available. Sedimentation again, has certain limitations the first is really interference from neighboring particles. So, what you are assuming when we do sedimentational size distribution analysis is that each particle is in free settling mode. In other words, there is no interference to the settling of one particle from its neighboring particles. Whereas as a concentration of the particle increases hindered settling, becomes more and more likely so, the presence of adjacent particles can actually start affecting the settling characteristics of the individual particle.

So, that introduces a source of error in your analysis, again the shape effect can be huge you can just image that if you have like a needle and it is introduced into the liquid in its

vertical form. It is likely to sink right through, but if we introduces it in a horizontal form it is slightly to float.

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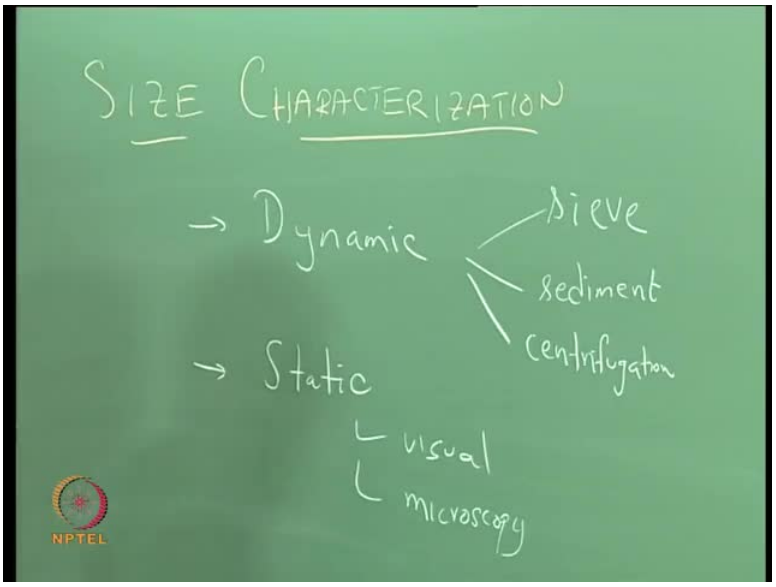

So, the shape effect is again an important parameter in sedimentation analysis, but the prevailing mechanism, the dynamic mechanism that you are using in this particle case to do your size characterization is the settling that is achieved by the inertia of the particle. So, it is predominantly a Stoke's number based effect and we will discuss in more detail in one of the feature lectures.

About centrifugation, I am sure you have done air classification type of experiments, where you take up again a population of particles introduces it into a chamber and then you introduce flow of air. so that the particle that are introduced. For example - from the top may get entrained in air that is blown from the bottom and particles of different sizes and different masses will be blown to various radii of this chamber depending on their size and mass characteristics.

So, the lightest particles are lightly to become fully entrained in the air flow and start following the stream lines of air flow, whereas the heaviest particles once that are most likely to deviate furthest from the streamlines of air flow. So, they would probably basically stick to the center of the chamber, whereas the lightest particles will be blown towards the sides and the circumference of the chamber. So, you achieve separation by

size and then, you can essentially capture the samples and to sieve analysis to characterize that size.

Now, in this case, the characteristic of a particle that you are using to do your dynamic size analysis is it is action and a centrifugal field, which is a supplement to the gravitational field that you experience in sedimentation. Now in centrifugation also there are limitations, which can be overcome in certain ways, for example a normal centrifuge would probable operated 100s of rpm may be a few thousands, but if you have very fine particles in the submicron range. For example, the forces will not be sufficient to cause separation of the particles, but there are what are known as ultracentrifuges? Where you can actually achieve 10s of 1000s rpm and then these forces are large enough to be able to separate even very fine particles.

The other problem, with centrifugal classifier I am sure you would know, if you have done the experiment is that there is always some overlap of the fractions, some of the course fraction leaves with the fine streams. Some other fines fraction stays with the course stream, so you do not really get a clean separation. There it is not a just a single sharp cut off size which is what we are hoping for in theory.

So, all these dynamic methods are very practical, very scalable, very useful they continued to be employed to a great extent, but you have to take that data with the pinch of salt, you have to first appreciate all the errors that are involved in the analysis and secondly realize that these are relative dimensions.

In the first case, you are talking about an interception equivalent diameter. The second case, you are talking about a settling equivalent diameter. In the third case, you are talking about essentially a body force equivalent diameter, none of these represents the absolute size of the particles that are under consideration, also these methods are not really suited for single particle analysis. They are predominantly methods that are intended for analyzing the bulk properties of powders to get an idea of the average prevailing size in in a powder, for example but they do not have the sensitivity for us to be able to take the analysis down to individual particle level and do size characterization.

In order to do that you have to use static methods, now static methods in comparison to the dynamic methods or much more pain full, very very time consuming, require a lot of expertise, expensive and then actually no more absolute than, these methods because the

sizes that you measure here. The difference is now, they will be at single particle level. However, they are still going to be relative to some metric that you use in your method of analysis.

Now, some common methods of static size analysis would be - the most obvious one is just a visual inspection, you have a particle sitting on a surface and you look at it and your eyes are doing size assessment that is an example of a static size measurement or taking it further microscopy, because when you say microscopy there are so many variance of it. The most simple one being optical verses electron and then you have techniques that are based on light scattering, techniques based on acoustic fields and so on. So, there is a large variety of techniques that are available to do characterization of particle size in a static mode and we will discuss these in more detail in the feature lectures.

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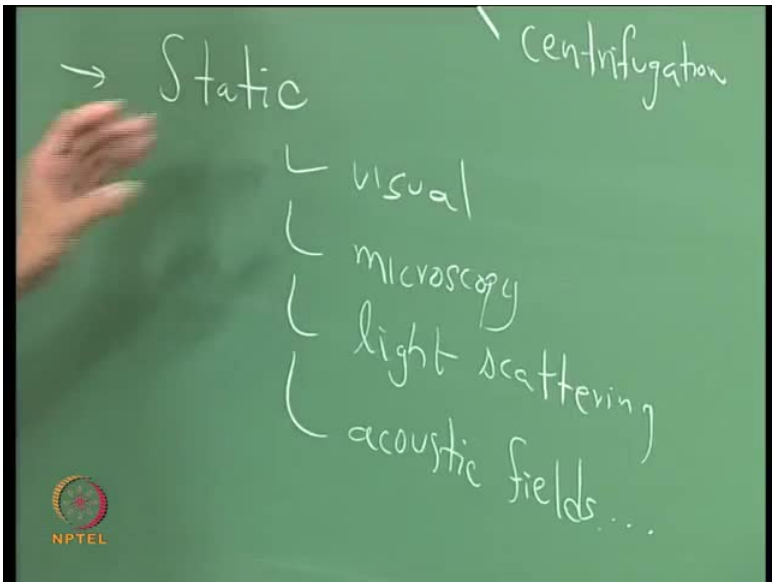

But the point I want to come back to here is - what is the requirement? What is the fundamental? First step if you want to do a static analysis of particle size, what do you have to do? First, before you can even start your analysis you have to immobilize the particle you have to first collect it on some surface on which you can analyze it.

Now that is not so easy to do, because especially as particles get finer and finer they want to keep moving, where diffusion velocities are very high; so, if you talk about

nanometer size particle, it is never sitting in one place, even within a second it could have moved millimeters, depending on the size of the particle.

So, doing a static analysis sounds like it is a very powerful and more informative way of doing size analysis, but the first challenge you have to deal with is how you collect the particles on to a substrate from which you can then analysis the size of the particle.

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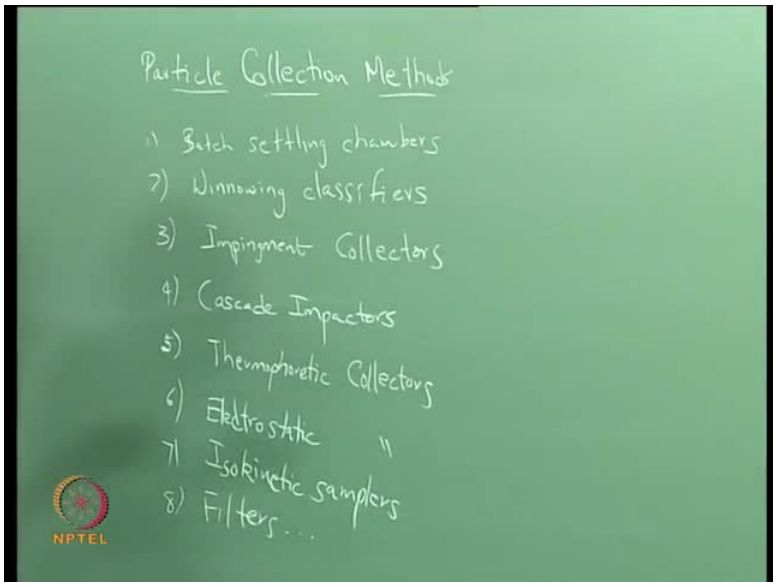

Now, when we talk about, methods of collecting particles for size analysis; there are several of them. There what are known as batch settling chambers, winnowing classifiers, impingment collectors, or impingment settlers, cascade impactors, thermophoretic collectors, electrostatic collectors, isokinetic samplers, filters etcetera.

Now, this may look like a long list, but it is actually only a subset of various methods that are used just for collecting particles. So, that you can then do a static analysis; so, even before we start discussing methods of static size analysis, you first have to understand how to collect the particles? So, that you can do the size analysis.

So, let us just take these and briefly discuss them, a batch settling chamber. Actually, the mechanism involved is very much like the sedimentation mechanism in dynamic size analysis. The difference here is you are using the settling chamber not for doing direct size measurement, by looking at the rate at which the settling is happening, but rather to

collect particles on to a surface, which is typically located at the bottom of this settling tank.

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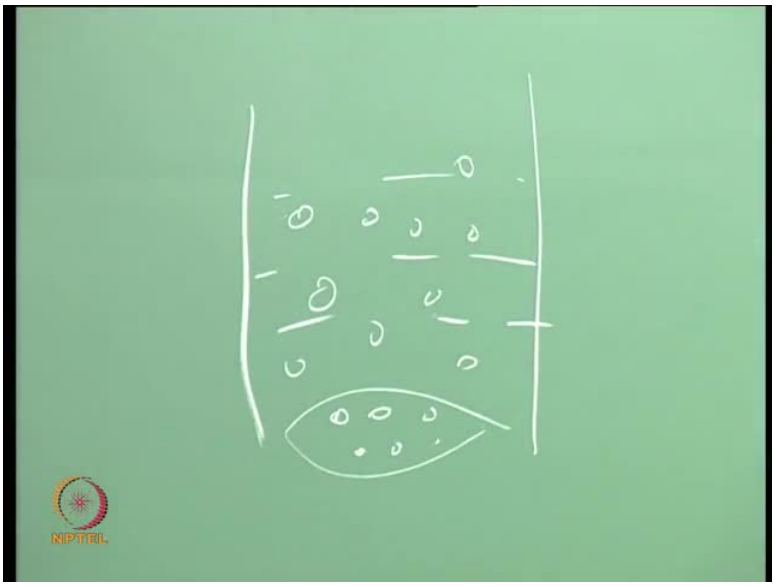

So, you will have collection surface here and you will allow the particles that are suspended in the liquid to collect on this surface over a period of time. And then you will remove this collector plate and analyze the particles on this collector plate. So, the mechanism is very different to the dynamic sedimentation size analyzer. The difference is here you are using the sedimentation mechanism simply as a collection device, not as a size analyzer.

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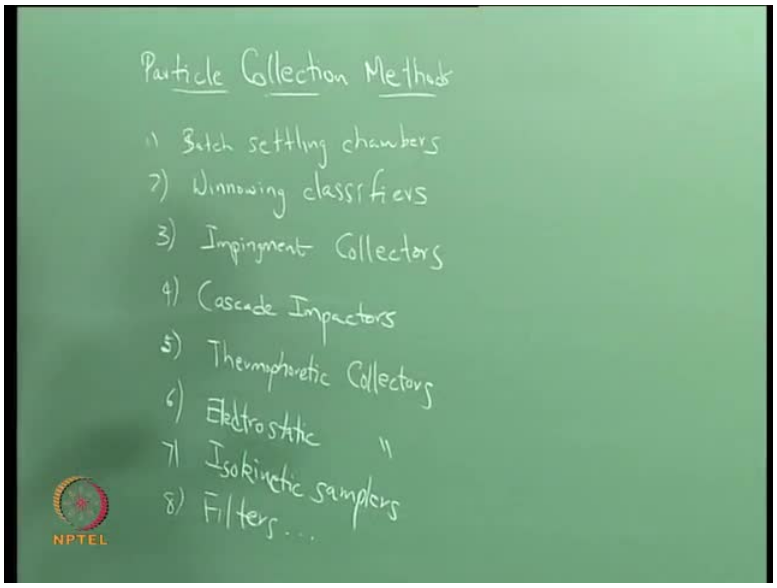

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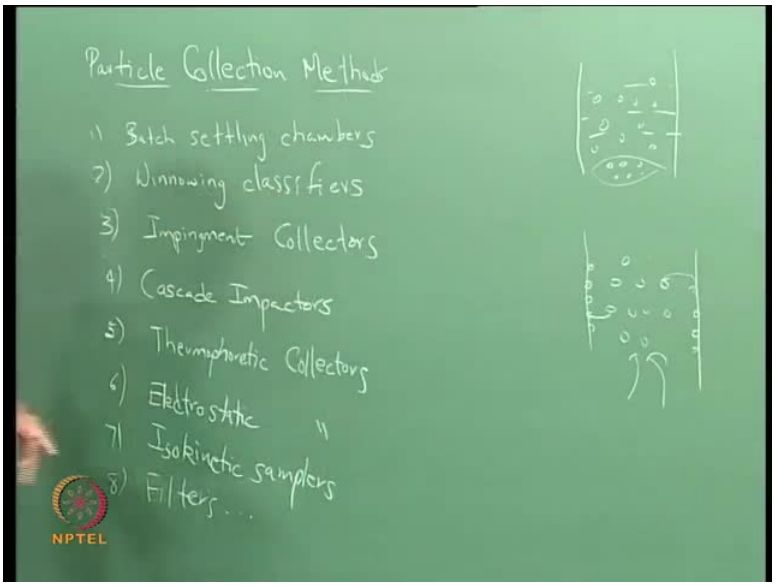

Similarly, a winnowing classifier works very much like a centrifugation device for a size analysis in dynamic mode except that here what you doing is you are using a centrifugal force to blow particles at very high velocities towards collecting surfaces. The higher the impact velocity the greater is the probability that the particle will stick to that collecting surface.

So, in this case, you will have air that is being blown in. For example through the bottom of the particles that are present in air will then be blown towards the size at the chamber

and they will actually collect on again plates or surfaces that are mounted on the sides of this device. So, here you are using this centrifugal force, essentially to enhance the force with which particles stick to the collecting surfaces. And then you will removes these plates and subject them to static analysis.

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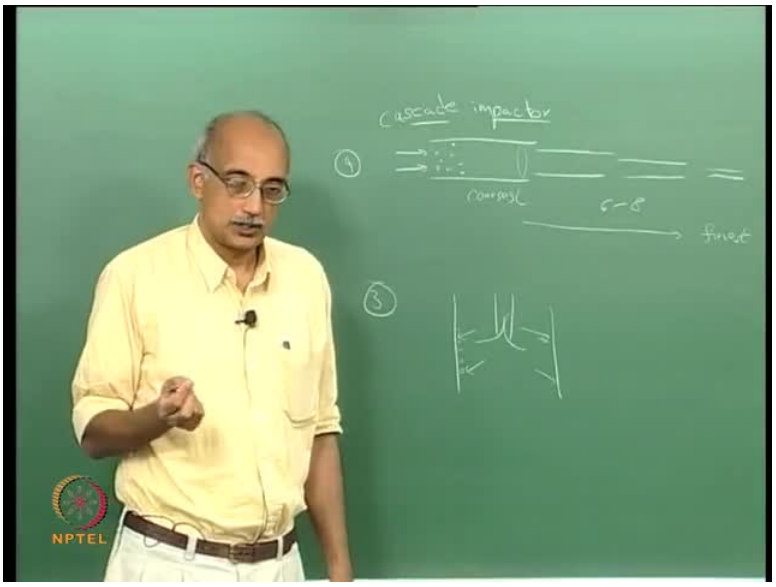

The third technique impingment collector is actually, very similar in principle to the winnowing classifier. The difference is that in this particular case you take, let us say that you have air that is containing particles, you essentially accelerate it through a cylinder of a certain dimension. And then you take it through multiple stages and at each stage the diameter becomes smaller and smaller.

Now, what is an idea behind doing this? You maintain the same flow rate and you keep narrowing the diameter, what is going to happen? The flow velocity is going to keep increasing, So, at each of these stages and there are usually 6 to 8 of these you have collector plates that are mounted, near the exit. And so the coarsest particles will get collected in the first stage itself. But the velocity of impact is not sufficient for finer particles to get collected in this stage. So, as you go down this way the finest particles will get collected in the last stage, because the acceleration velocity is highest in that last stage of collection.

So, this is a way of again collecting the particles, while at the same time classifying them, whether a classification is a word that we will use repeatedly. Classification refers

to separation of or size separation of particles based on a certain physical property of the particles.

So, in this case, we are size separating particles based on their impaction and sticking probabilities. So, once you have done this then you basically, take each of this collection plates and do your static analysis this method is very powerful, because you have now classified the sizes also. So, you can take the collector plate from the first stage and just look at it may be with naked eye, or with an optical microscope that may be sufficient, because the particles are very coarse, whereas the particles that you pick up from the last stage are likely to be very fine. So, you probably have to take them in for SEM or TEM analysis to do the size characterization.

The next technique is cascade, I am sorry, this is actually the cascade impactor technique, it is essentially an arrangement in which we have a cascade of collecting plates and we are making use of the impaction of particles to do the collection.

The one we skipped over, impingement collectors. So, let me attach each one of these with some numbers. So, this is a representation of 1, representation of 2, this is the representation of 4, 3. And impingement collector is actually close to a winnowing classifier in the sense that it is done in a single stage, but the only difference is that instead of using centrifugation to accelerate the particles, you actually introduce them as jets. So, that they are in trained in high velocity fluid and so the particles are made to impinge on the surfaces and collect at these locations by introducing them through the center through high velocity nozzles.

Now, the difference between impingement and impaction is actually very settle and we will deal with this in one of the later lectures. The difference primarily is that in impingement particles are slightly smaller than particles that you normally associated with impaction. And the mechanism of collection is also certainly different in impingement particles that are flowing parallel to the surface, can also be collected as long as their size is such that and the stream line, is such that the particle comes in contact with the substrate. So, it is a contact collection mechanism. As soon as, the stream line of particle flow is such that it brings the particle in contact with the surface it gets collected that is what we call impingement.

Impaction on the other hand is very different, the particle actually deviates from the flow stream lines and normally impacts the surface and it gets collected, because of the high sticking coefficient that is associated with high Stoke's numbers. So, the impingment collector is a way to collect particles in a slightly finer size range compare to what you can normally collect in a cascading impactor.

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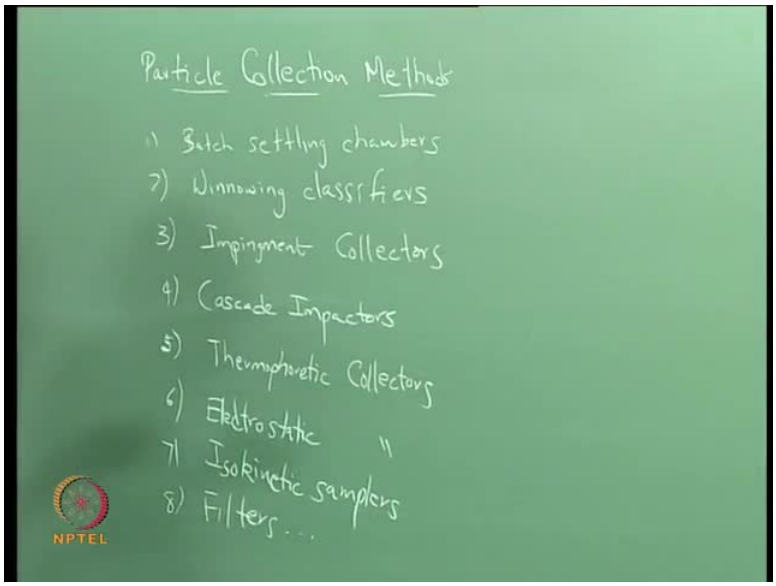

5 and 6 essentially make use of the effects of applied force fields. On the transport of a particle for example, if you take a chamber in which you have a strong thermal gradient a high temperature region and a low temperature region. And you locate, your collector in the low temperature region and you apply a high temperature, where the particles are being introduce into the chamber.

Now, particles have a tendency to always move down a temperature gradient, it is called thermophoresis; so as soon as you establish a thermal gradient particle, start moving from the hot zone to the cold zone. So, you locate your collector in the cold zone, so the particles automatically drift towards the collector and you can then pick up the particles and subject them to static analysis. Similarly, electrostatic collectors make use of an apply electric field to do the separation. Here the particles can either be artificially charged before they enter such a chamber or we can even make use of the natural charge that they are carrying in.

The classic example of this is the electro static precipitator that is used for collecting fly ash in power plants. And here again the idea is that particles can be directed to move towards a particular surface by taking advantage of charge differentials. So, you can preferentially collect particles of a certain, polarity on a certain surface and then subject them to further analysis.

Isokinetic samplers are sampling devices that essentially, collect particles by aligning themselves parallel to the flow direction. What are the difficulties in sampling, when you have particles that are suspended in a fluid and flowing and you want to grab a sample for doing your static analysis. The uncertainty lies in the fact, that you do not know that the sample that you have grabbed is truly representative of the particle population that is in the fluid to begin with because, your sampling process itself introduces a variability.

Now, isokinetic sampling essentially means you use a sampling probe through, which the fluid flows at the same velocity as it is flowing in your process chamber.

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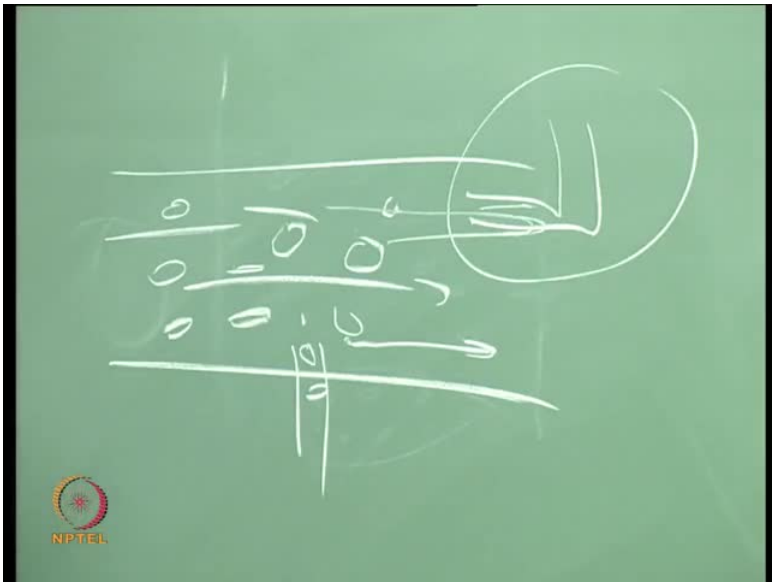

So, for example, we can consider two cases; let say that you have a pipe and the flow is in this direction and it some fluid that has particles in it. Now, how do you sample and collect particles from here for static analysis, you can do it let say in two ways you can put a tap this way and collect particles or you can provide the tap this way and collect the particles which do you think is superior; this one because here the fluid and the particles are going to be flowing through your collector essentially at the same in the same

velocity and same direction as in your process chamber, whereas here you are actually collecting particles, orthogonal to the flow of the fluid. So, the particles that are going to be collected in this case are those that do not follow the stream lines.

So, in a way your kind of defeating the purpose; so isokinetic sampling refers to the fact that the way you collect particles, for your analysis must be such that your sample is as representative of the original fluid system as possible. And isokinetic sampling, which literally mean sampling at the same velocity is one way of ensuring that happens.

The last technique here is filters, and this is something I am sure you are all very familiar with we always use filters to collect particles for analysis. There are two types of filters membrane filters and fibrous filters the mechanisms involved in filtering particles are very different, in these two types of filters and therefore the size ranges that you can collect with the two types of filters are also very different.

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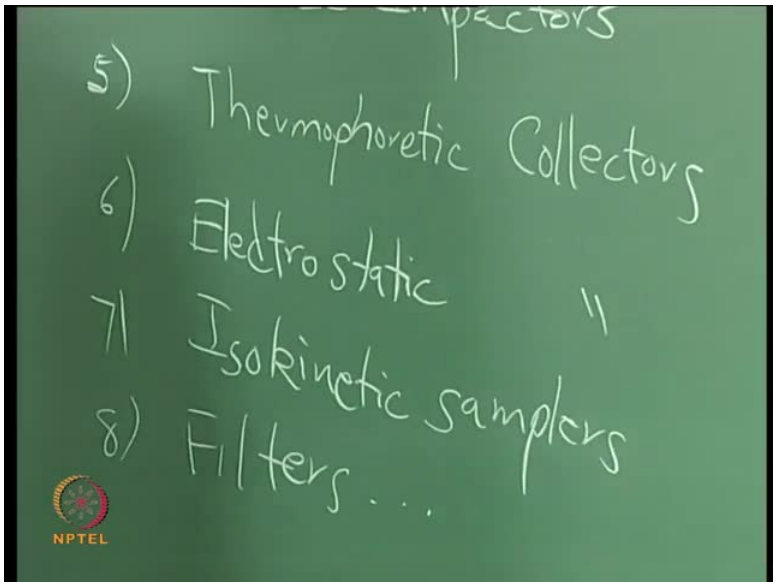

So, there are some tricky elements involve in selecting the appropriate filter for doing the analysis that you subsequently want to do, but of all the techniques that you have listed filters are probably, the one set are most widely used to collect particles, for various purposes whether it is for doing subsequent analysis or it is actually for collecting material, for example nano particles for use downstream in your process.

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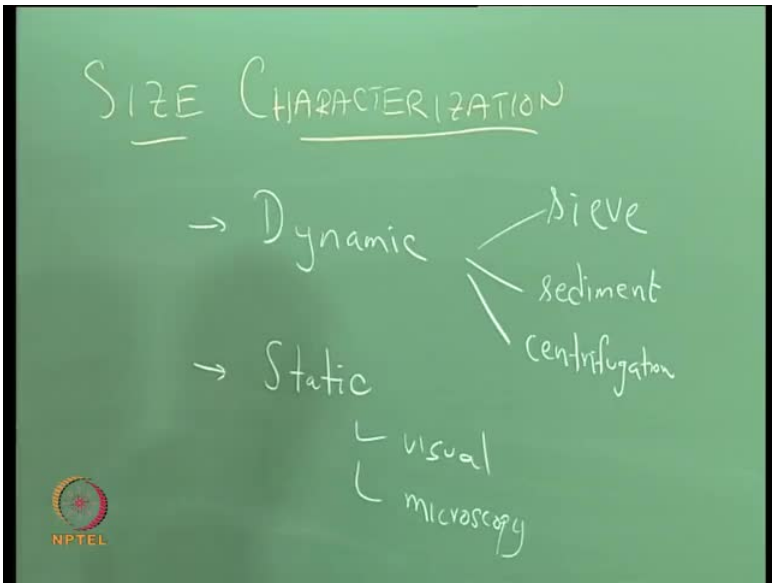

So, many of these techniques that we have talk about, involve certain aspects of particles, characteristics of particles, which we will deal with in more detail in future lectures, but right now, I just want the give you an idea of the various methods by which we can collect particles for subsequent analysis.

So, starting in the next lecture, we will start detailing some of these static analysis methods that can be used for quantitative size analysis, we will stop at this point in this lecture, any questions, see you at the next lecture.