Particle Characterization

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Module No. # 03
Lecture No. # 09
Morphological Characterization:
Particle counters

Welcome to the ninth lecture in our particle characterization course. In the previous lecture, we discussed light scattering characteristics from single particle and how that could be used to estimate the size of the particle. One of the key points when we try to use light scattering as a way of size measurement is the fact that the scattering intensity scales as the particle diameter 2 to the power 6.

So, as particle size drops, the scattered signal becomes increasingly weak, and once you start approaching the submicron dimensions, the scattered light signal becomes too weak in comparison to the noise, and therefore, the method becomes untenable. So, we discussed a way to addresses issue which is essentially it use these very fine particles as a condensation nucleus and condense a film on top of these particles to grow them to a size where they would then be detectable by a light scattering instrument.

Now, one of the challenges as I mentioned is that it is very difficult to trace back the original size of the particles from measurements that we do on particles whose size has been enlarged due to this condensation process, and obviously, we would want to recover information about the original particle size distribution. So, how do you do that?

Well, the technique that is popular in that regard uses something called a diffusion battery. It takes advantage of the fact that as particle becomes finder and finer the predominant transport mechanism becomes diffusion, and diffusion is a process whose rate actually scales inversely to particle size. So, as the particle size drops, their rate of diffusion increases very rapidly.

So, the thinking is if you can take a stream of particles, in which you have a variety of sizes, and then, use this diffusion screen or diffusion battery to classify them according to size based upon their diffusion characteristics, then you can segregate these particles into specific size buckets, and what you can then do is in your condensation particle counter or condensation nuclear counter, you can selectively draw samples from each of these channels and do the enlargement using condensation as a process, measure the size, but the difference is now you are dealing with particle in a much narrower size range compare to the original sample to you started it.

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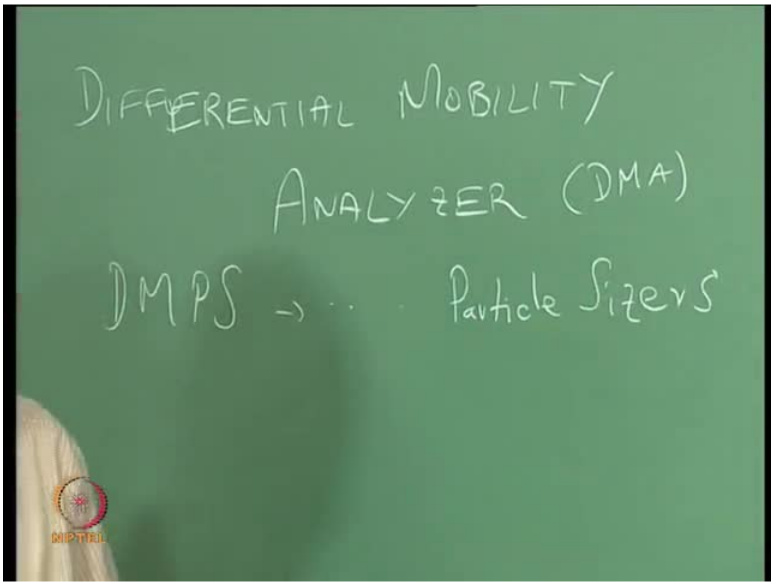

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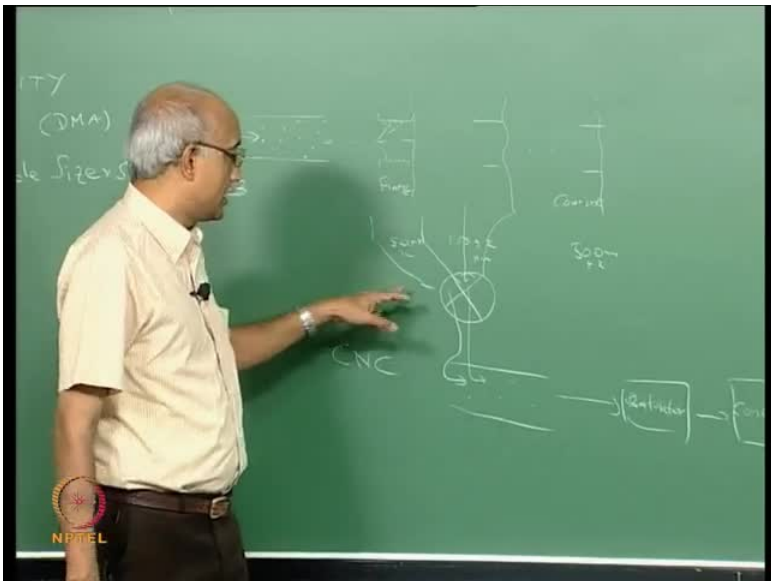

So, this type of arrangement is used in instruments that are called diffusion, actually differential mobility analyzers or DMA, they are also known as DMPS - it stands for differential mobility particle sizes, and so, the principles again is these instruments take advantage of the fact that in the submicron range, the mobility of the particles is very much of function of the diffusion coefficient which is an inverse function of particle size. So, what you could do is let us say that you have a stream of particles that are suspended in a fluid and it is flowing in this direction. You may recall that we had looked at the similar setup in the larger particle size ranges where we looked at cascade impactors.

If you remember the principle behind a cascade impactor is almost exact reverse of the principle behind a diffusion battery. In a cascade impactor, you take advantage of the fact that larger particles have greater kinetic energy. So, again, if you use a set of screens, the largest particles will most likely be captured in the first screen itself, and then, the smaller particles will be successively accelerated to greater velocities by narrowing the diameter of the chamber to improve the capture efficiency. So, in a cascade impactor, you are again classifying by size but the largest particles will get capture in the first frame and the finest particles will get captured in the last frame.

A diffusion battery works on a very similar principle expect that in this case, the finest particles will actually be captured in the first screen and the reason for that is the as the particles are going for or flowing in this direction, you have various cells that are setup like this, and the capture screens or offset from the flow direction and they are located in such a fashion that in order for the particles to get captured, they must actually defused to the screen, and so, as the particles are flowing through the finest particles, because they have the largest diffusion velocities will deviate first from the flow path and get captured on this screens.

So, these are typically just stainless steel wire measures that are setup at different sizes. So, the finest particles will get captured in the first set of screens, and similarly, you will have an arrangement that stretches all the way out to the coarsest particles in the stream. The coarsest particles will have the smallest diffusion velocities.

And they are most likely to follow the stream lines of flow. So, essentially if you look at this last screen in this diffusion cell or diffusion battery, it will have a predominance of the coarsest particles in the fine particles size range, and therefore, it will get captured in the last screen. So, what you have effectively done is a classification by size.

And there will be an enrichment of particles, let us say that this population ranges all the way from 50 nanometers to 500 nanometers. These particles are likely to be in the 50 plus or minus some x size range nanometers, whereas the next may be the 100 plus or minus x nanometer size range and so on, and the coarsest one will contain 500 nanometers plus or minus x.

So, by suitably designing these meshes and the distance of separation between these meshes, you can get as fine as separation as you want. So, how do you incorporate this within the condensation nuclear counter that we talked about last time? If you recall, the condensation nucleus counter essentially takes a stream of particles and it actually condenses material on it, so, you have a condenser stage.

Actually first you do a saturation, so, you have a saturator which is set a slightly higher temperature followed by a condenser which is at a slightly lower temperature, and the exit stream from the condenser goes into the laser particle counter or light scattering particle counter. So, this is what we had sketched yesterday has is or in the last class as our condensation nuclei counter.

And this is what we are calling a diffusion battery. So, the way this works is essentially you have a valve here which will be set to successively accept the output from each of these cells. So, initially, this valve will take in all the particles there are captured in the first mesh and that will be input into the condensation nuclear counter and the counting will be performed.

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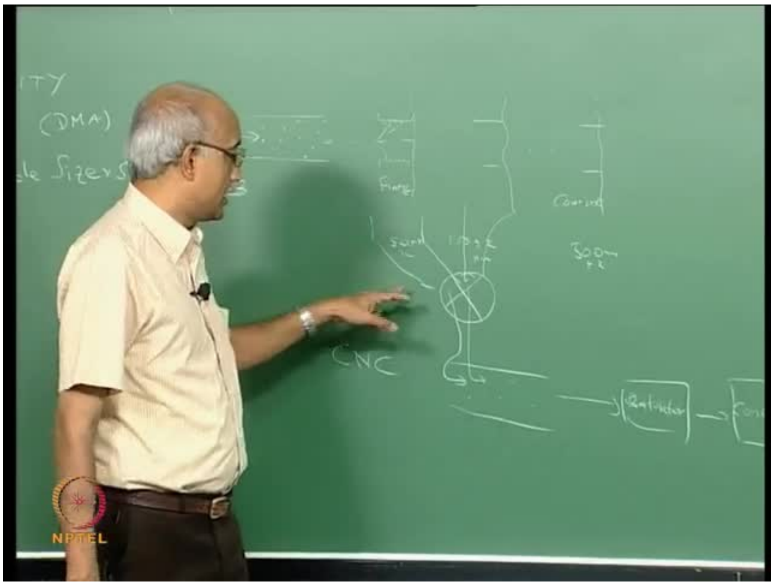

After that sequentially the second cell will be allowed through this open closed valve to enter the condensation nuclear counter and the particles in that screen will be counted, so, essentially, by using this very simple setup of a valve that just turns and allows different streams to enter. You can now do your particle counting on very finely divided particle size ranges.

So, this setup, when you combine the diffusion battery in combination with a condensation nuclear counter is what we call differential mobility analyzer or a differential mobility particle sizer and it can give us reasonably conclusive data on the size distribution of the particles that were originally present to begin with before you start at condensing material on to it.

In order for this to work in an absolute sense, you still needs to do some calibration either experimentally or theoretically, for example, based upon the particle diffusion characteristics which we will discuss later in the course. You can actually calculate what will be the size that is captured in that first mesh; so, that gives you a pretty good idea of what the size should be.

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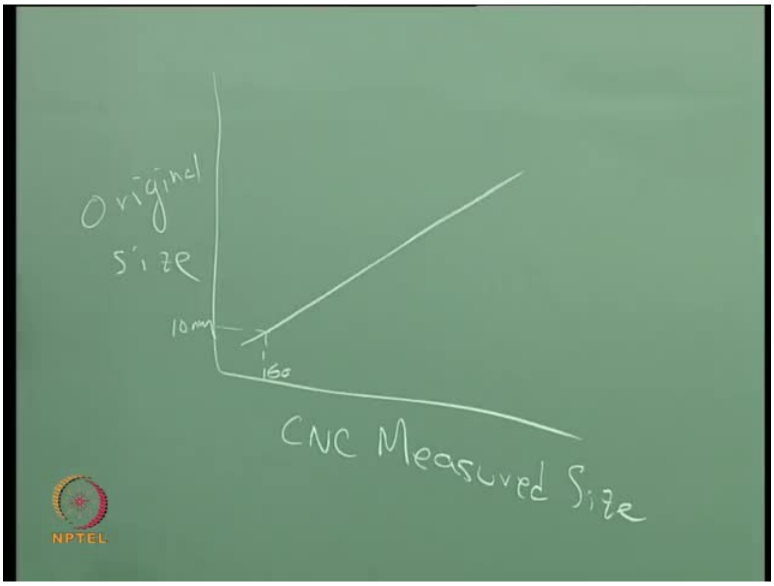

And the, and therefore, once you collect data using the condensation nuclear particle counter, you can essentially graph the original size to CNC measured size and you can show basically that there will be a correlation between them. As the CNC measured size, this will always obviously be higher than this, so, every point here, for example, the measured size may be 16 nanometers and the original size may be 10 nanometers.

So, similarly, there is always an offset, this is not a 45 degree line with equal axis, because the measured size is always larger than the original size, but once you have gone through this exercise once, you can actually use these calibration curves to establish what the original size was once you know what the actual measured size was.

So, the development of this methodology has given us an ability to extend, however, light scattering based particle size measurement into even the submicron and nanometer size ranges yes

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Well, again, there are, there are really two ways to do it. The calibration can be theoretical because what you are really measuring is only this and you are still estimating this, but you can actually, theoretically calculate what this size was. In other words, because you know the mobility of the particle as a function of its particle size, you know that particles are captured in the first mesh have to be within a certain size range.

And therefore, you can establish what the size is. Similarly, for each of the measured sizes, you can theoretically calculate what this is and develop this line. That is one way to do the calibration. The other way is to use an independent measure, so, for example, when you collect the samples from the first mesh, you subject then to the CNC measurement. You can essentially repeat the same measurement with a new set of sample.

But this time, all the particles that you collect in the first screen, instead of using a condensation nucleus particle counter, use an independent measurement technique, for example, take this set of particle that you have collected and use a tunneling electron microscope or a scanning electron microscope with sufficient magnification and actually do size analysis.

It is very painful, you know, very time consuming, laborious, but you can do it as a onetime activity as a calibration activity. So, this calibration curve can essentially either be theoretical or it can be based on actual measurements performed on the samples using in independent technique which does not, which is not scattering related; it could be simple microscopic inspection or it could involve other techniques such as acoustic field scattering and so on, but it needs to be independent measurement method.

But it is also true that the finer the particle, the easier it is to theoretically predict it is flow behavior, because diffusion becomes absolute dominant effect. So, as long as you avoid other gradients in this system, such as, a thermal gradient or the presence of an external field, you can predict much predict how this particle is going to move as a function of time. So, that makes calibration even theoretically quite feasible and

Productions could be done the more than 95 percent (( ))

Theoretically sure, I mean particles once you know, I mean that the basic assumption is still going to be regarding the shape, you know, because most of our calculation are still based on sphericity. So, the error in your theoretical analysis will very much depend on how spherical the particles are the closer to, you know, sphericity in shape the better your theoretical calculations would be, but if you use the experimental method of calibration, then your accuracy is very good but it is not easy to do and it is not a very good use of either your time or instruments time.

So, particle counters are clearly very very powerful. Especially, particle counters based on light scattering or now widely used to measure particle sizes in a size range all the way from nanometers to at least 25 to 50 micrometers. Once you go above that size, you are probably better of using optical inspections techniques, direct inspections techniques.

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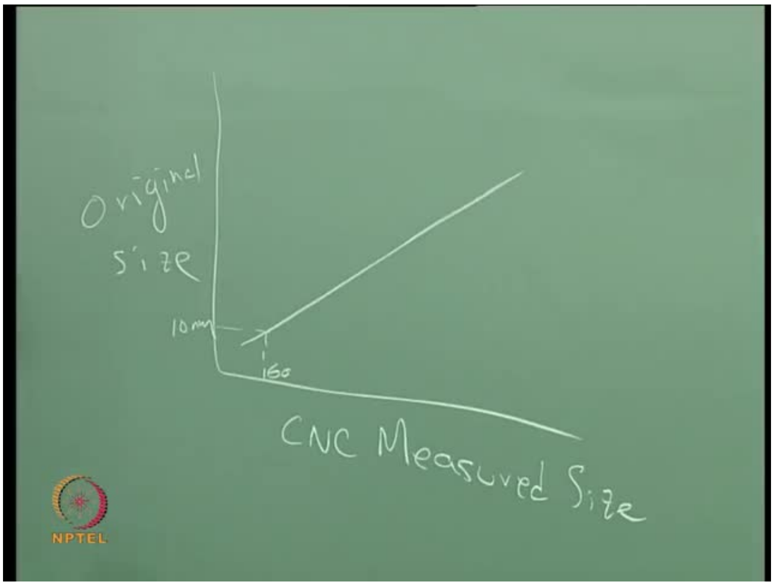

But as we discussed earlier, the fact that lights scattered from a particle is indicated not only of its size but is dependent on so many other parameters associated with the system, means that it is very difficult to take the reading that you get from the particle counter and assume that is it is the absolute size of the particle, it is always relative, and so, you have to understand what these relative dependencies are and it is also important to design and operate a particle counter or particle size analyzer, in such a way that you minimize the errors in the measurement.

The use of particle counting and particle sizing is obviously critical in many industries. For example, in the semiconductor manufacturing area or in a any precision assembly like (( )) and so on, particle counters are widely used to assess the level of particle contamination in a clean room or on the product.

So, they are really the key to achieving reliability and quality of the product from a particle contamination view point, but on the other hand, if you are actually trying to synthesize nano particles, then again the use of particle counters and size analyzers is very important in order to precisely determine the size distribution of the particle that you have achieved.

And so there is no question that sizing and counting of particles is a very important discipline, and methods based on lights scattering gives us the ability to do it in a much more convenient and rapid manner compared to microscopic inspection techniques which are more suited to qualitative characterization. Given that, the particle counting as a technique, as an industry has evolved over the years to being something that has become extremely reliable.

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A → Accuracy
P → Precision
R → Repeatability & Reproducibility
L → Linearity
D → Dynamic Range
S → Sensitivity
R → Resolution
U → Uniformity

There are certain basic characteristics that a particle counter must satisfy, and there is an acronym based way to remember these characteristics, just remember A P R L D S R U; A stands for accuracy, P stands for precision, R stands for repeatability, L stands for linearity, D stands for dynamic range, S stands for sensitivity, R stands for resolution and U stands for uniformity. So, let us talk about what these are. Accuracy is a measure of how close you are measured value is to reality.

How close is it to the actual value that you are measuring? For example, if you are using a particle size analyzer to measure size of a particle, how close is your measurement to the real size of that particle, or if you are using a particle counter to do counting as well as sizing of the particles, then you really have two matrix - how close is your count to the actual count and how close is your size to the actual size. So, accuracy is a measure of how well measured values relate to reality.

Precision is a slightly different parameter. It is a measure of how meaningful or small increments in the readings that you measure. For example, if you measure one particle as 15 nanometers and the other particle as 16 nanometers, is that real mean is that a meaningful increment or is the noise in the measurement sufficient that 1 nanometer increment in size that you measure is not really valid, it is not really legitimate.

Repeatability, actually R stands for both repeatability and reproducibility which are slightly different things. Now, when you are using any instrument to measure any value, you are always interested in knowing how repeatable the measurements are and also how reproducible the measurements are. The difference is repeatability refers to when the same operator performs the same measurement on the same sample.

How repeatable are the data because how close are the second set of readings to the first set of readings. Reproducibility refers to something else. Let say that one operator has collected a set of values on a sample. Suppose, you bring in a second operator and have that person do the same measurement on the same sample, how close is that reading to the reading that was taken by the first operator? So, very different things but the error in the measurement is actually a cumulative measure of both the repeatability error and the reproducibility error, in fact together, they are called gauge capability error.

The gauge capability includes repeatability as well as reproducibility and it is typically expressed as a percentage. The gauge capability of an instrument must typically be better than 10 percent of the signal; otherwise, it is not considered an acceptable value.

Linearity basically refers to how these three values - the accuracy, precision and repeatability / reproducibility - vary with the range of measurements that you are doing. For example, again in a particle size analyzer, the range may refer to the minimum size and the maximum size that you are measuring. It is not enough that you achieve accuracy, precision, repeatability and reproducibility at one value in your range, say on the low end or at the high end; these values have to be achieved through the entire range of measurements.

They may be different, in fact, in particle counting and size analysis, we will frequently notice that the error in the measurement actually increases as the concentration of particle changes. Some techniques such as light scattering work better on more dilute samples. Other techniques which we will discuss later on, such as, acoustic scattering actually work better when you have a greater concentration of the particles in the sample.

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So, you would not expect that accuracy, precision and repeatability, reproducibility will remain constant over the entire range of measurements. However, what we would like to see is that it is not a non-linear dependence. So, for example, if you measure over a size range of, let say 50 nanometers to 5 microns and let say that you are measuring repeatability plus reproducibility error as your metric.

What I am trying to say is this will not remain constant over this entire size range. However, it should not exhibit highly non-linear behavior; in other words, you should not see a trend where there is a huge spike in this error at some value, and then, it drops of on either side of that value.

What you would like to see is a nice gradual and linear dependence of this parameter on size. Given that in a particle counter it is more difficult to count and size final particles compared to larger particles. This is the kind of behavior you would expect that the error would slowly decrease as you go to larger sizes. However, there is the other factor that as the particle counts decrease, the error will increase. Now, in nature, we have a tendency to see that particle counts always follow a certain pattern.

There are always more fine particles compare to course particles in any population. A thumb rule is for every particle that you can see, there are at least a thousand particles that you cannot see but which are present. So, particle counts actually tend to decrease as a size increases; which means that the error is likely to increase if you are doing counting and sizing of particles in the larger size range compared to the finer size range.

So, these two effects kind of go in conflict with each other. Some errors increase as particle size increases, but then, because of the associated decrease in counts, some errors increase, so, the net effect may be something that is slightly has a decreasing slope or it may have a slightly increasing slope.

So, this behavior is considered acceptable; this behavior is considered acceptable, but if you see highly non-linear dependencies and trends, then there is something wrong either with the optics of your system or with the software, that is being used to analyze the data or it could be that the particle samples itself really does not lend itself to light scattering analysis. For example, you may be operating in a range of dilution which is too concentrated for a particle scattering type of analyzer to handle. So, you have probably better off switching to a different methodology all together to evaluate the sample rather than using light scattering as a technique.

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Dynamic range is essentially the range in which the particle counter operates. So, for the case that we have sketched over there, the range would be from 5 nanometers to 5 micrometers, yes, the sensitivity parameter again it is difference from accuracy and precision and resolution; sensitivity is the smallest particle that you can measure with the particle counter.

So, in the case of that instrument, it is sensitivity would be 5 nanometers, because that is the smallest size in the range in which that instrument is operated. Resolution on the other hand is slightly different; the resolution is a measure of how closely two particles can be positioned in the sample but still be measured or identified as separate particles.

Now, that number typically will be larger than the sensitivity parameter, and so, an instrument that can measure down to 5 nanometers may not be able to distinguish particles that are, let say 10 nanometers apart, in which case there is always a question mark over the data. When it says 5 nanometers, is that really 5 nanometers or not. An especially in the larger sizes, if such an instrument is measuring, let say 100 nanometers, you are not sure if that is 250 nanometer or 10 nanometer sized particles or really 100 nanometer particles.

So, resolution refers to the ability of the instrument to tell a single particle apart from an agglomeration of particles, and finally, uniformity refers to all of these seven previous parameters and how the position of the measurement within the sample affects these parameters.

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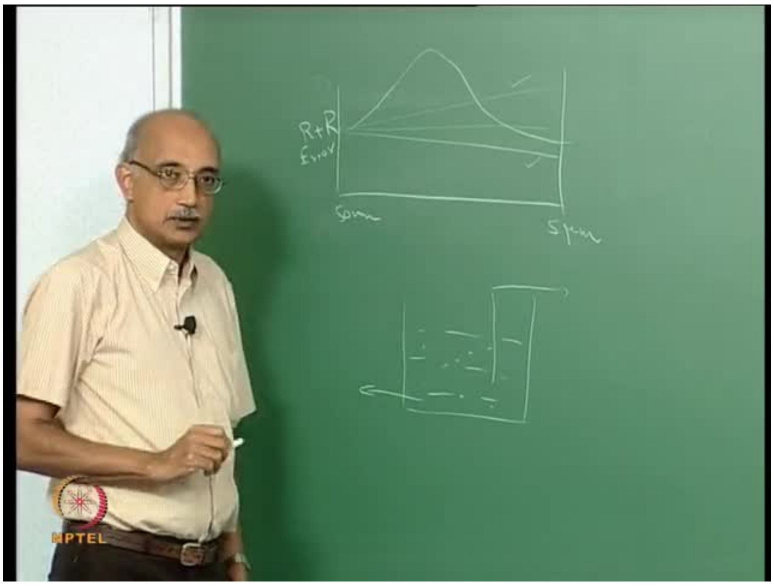

So, if you have a beaker, in which you are doing the measurements, and you have the particle suspended in a fluid, your initial set of readings may be taken from this point in your sample; the second set of readings may be taken from a different point in your fluid.

Uniformity refers to how close are these two values in terms of all these other 7 parameters, in terms of precision, accuracy, resolution, sensitivity, repeatability, etcetera, how much of a variation do you see by position within the sample? Now, this is an important characteristic, because if your sample is not well stirred, well mixed and stable, then the uniformity is going to be very poor.

So, for example, one of the challenges in giving with nano particles is the tendency to agglomerate, so, you may find that in the case of particles that are highly mobile within the suspension, there is quite a bit of non-uniformity in your sample because of the tendency to form localized clusters of particles.

So, that will be an indication that you have to use some stabilizers to keep the particles in position in the solution before you start doing size and count measurement. Another thing that can happen is simply that your sample that you have prepared is not well dispersed; it is not well mixed. So, in such a case, what you want to do is use a starter or some kind of a mixing mechanism to ensure that the population is made homogeneous before you do your sampling.

So, actually if you look at commercially manufactured particle counters in the sampling stage, they will always have a stirring facility. The stirring will either be done using a magnetic stirrer, that is actually inside the beaker or it can use ultrasonic such a way of mixing the fluid.

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But something has to be done typically to ensure the uniformity of the sample before you start doing the counting and sizing. So, going back, given that all these characteristics have to be satisfied in a particle counter, it is clear that the readings that you obtained from a particle counter, the quality of the data very much depends on how well controlled and how well characterized and how well calibrated the operation of the instrument is. Now, calibration again is a very important step because it makes the bridge between the data that you obtain from your instrument to something that is traceable as an absolute standard.

So, for example, if you use a particle counter that satisfies all these criteria and you get a certain size distribution. The thing that you will always worry about is can I rely on this data? How absolute are these numbers? If you do not have a way to reference this data to an absolute standard, you can never answer that question in a deterministic way. So, there are standards organizations all over the world which have essentially taken up the task of establishing these standards.

So, in the US the national bureau of standards which is now known as national institutes of standards and technology, does the job, and similarly, in India, we have a bureau of standards. They provide absolute standards that you can calibrate your instruments against. Now, these standards are also known as goal standards because they are absolute and non-varying.

So, for example, in the case of particle counting, the goal standard still remains collecting the particles on a filter and using microscopic inspection to do counting and sizing. The microscope that you use will be different and even the filter that you use to collect the particles will be different depending on the size range that you are interested in.

For example, if you sample only has particles that are 100 microns and larger, then you can actually use a fairly course membrane filter and use an optical microscope as your absolute standard to do the calibrations against. On the other hand, if your samples has nano particles, then your collection may have to be done on a fibrous filter, and then, the particles would need to be extract from the fibrous filter into another medium for doing the microscopic inspection, and you may need to use a scanning electron microscope or tunneling electron microscope at very high magnification to obtain your goal standard data.

So then what you do is take the readings that you get from your instrument, compare it to the readings that you get from the goal standard and verify that your instrument is calibrated. Now, that becomes a fairly laborious process once again, and so, what people have tried to do is establish what are known as silver standards.

A silver standard is essentially an instrument that is based on the same principle as yours, for example, if you are using a light scattering instrument in your lab to do size measurement, then you set up a silver standard which is also a light scattering based particle counter except that it is used only in a very controlled environment and it is only used for the purpose of calibrating other particle counters. So, these are known as silver standards.

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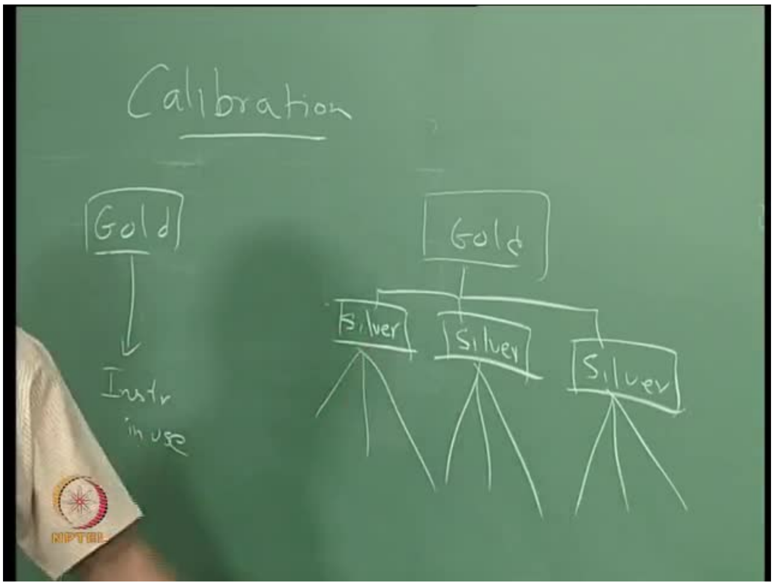

And the silver standard is calibrated against the gold standard. So, the calibration becomes essentially a two-step process - you can either use a gold standard and use that to calibrate your instrument in use or the alternative approach is to use a gold standard to calibrate several silver standards which can then be used to calibrate the individual instruments that are used in various labs, I mean this basically gives you a lot more flexibility in terms of how you do your calibration the turnaround is much faster. Instead of every one trying to calibrate that instrument against a few or a single gold standard, this enables you to do calibrations in a in a much faster way. Is the calibration as good as this in principle? Yes, I mean it should not matter whether you are calibrating directly against a gold standard or you are calibrating against the silver standard which is calibrated against a gold standard.

As long as this calibration is done carefully and these are done carefully, the quality of the calibration should be about the same. Now, calibration though is only one aspect of determining whether an instrument is working properly. The other aspect is what is known as correlation.

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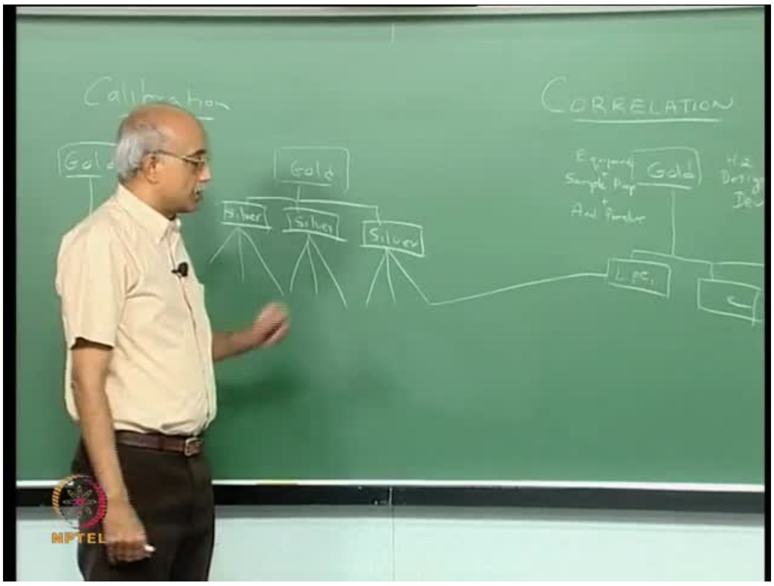

The difference between calibration and correlation is very settle but very important to understand. Calibration is really a measure of the instrument itself, for example, if you are using a laser based light scattering instrument, it is a measure of how stable is the laser.

Is this laser starting to lose its life? Is it starting to drift? So, it is very equipment focused. Calibration on the other hand is procedure focused, because for example, when you are using a laser particle counter to measure size and count, the instrument itself is doing its job, the optics are collecting the signals, this software is processing the data and so on, but the preparation of the sample is still in your hands.

And if you make an error in how you prepare the sample, then you does not matter, you know, how close to gold standard your instrument is your data is still going to be erroneous. So, calibration only refers to ensuring that the instrument itself has not drifted too far from its original settings which is very important to do, but correlation kind of completes the exercise by ensuring that the process that is being used to produce the data by analyzing the sample is also identical across various labs across various manufacturing facilities and so on.

So, in correlation also you will typically have a gold standard but this gold would be difference from this gold in the sense, it is not just equipment, it is actually the entire process. So, this is typically done at the headquarters of a manufacturing company or it could be done in the design and development center. So, they will have highly trained operators and engineers to do supervision who will ensure that the sample is analyzed in a certain way, and so, this includes the equipment part plus sample preparation plus the analytical procedure.

And then this will be compared to various sides specific instruments and so on. Now in a sense, there is no separate gold and silver here, because the reason that we have a gold and a separate silver here is because a gold standard can be absolute, whereas, here even what we are calling gold in terms of correlation is not an absolute standard, it is a standard that is set by individual manufactures using best practices in terms of how this sample is prepared, how the measurement is done, how the data are collected, how the data are recorded, how the data are interpreted and so on.

So, this is a quasi-gold standard and it is used to calibrate and correlate various counters and size analyzers that are in use across various facilities. So, this procedure when you combine it with this, so, the assumption is these particle counters have already gone through the calibration process; so, this is the second step, you do not even attempt correlation until you have completed calibration.

Now also when you talk about calibration of particle counters and size analyzers, there are really two aspects to it - one is the size calibration and the other is the counter concentration calibration. Now, those two are again very different, because if you are only doing count calibration, then that is once again primarily a measure of the sensitivity and other properties of your instrument itself.

You can prepare a set of standards which may be particles of a known size, and by the way the most commonly used standard is polystyrene latex - PSL - as it is known is widely used as the calibration material.

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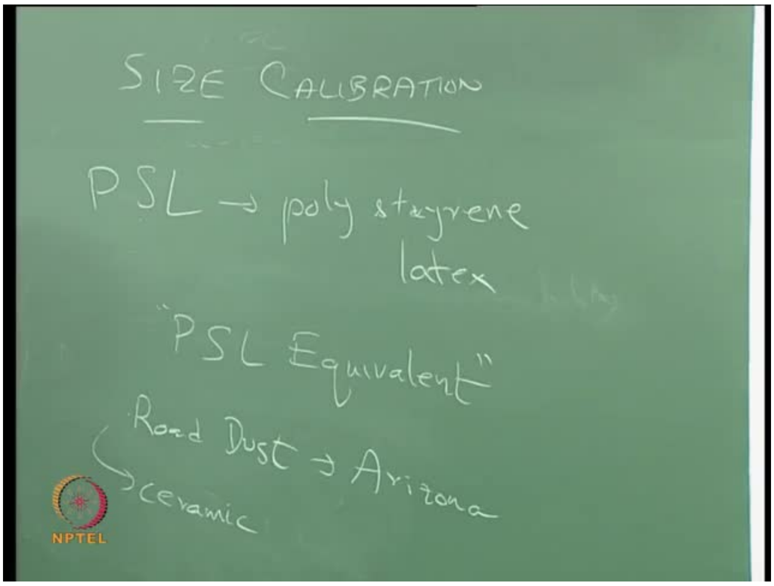

SIZE CALIBRATION

PSL → poly styrene latex

"PSL Equivalent"

Road Dust → Arizona

Ceramic

For size calibration because polystyrene latex is cheap, it is widely available; it is very stable over time; it is non-reactive and it is available in spherical form; it is the of all the standard materials that are available to us PSL has the best sphericity characteristics, and also, it can be prepared in mono disperse solutions of various sizes. Again a mono disperse solution is one that has a single characteristic size.

And it is very easy to make PSL standards of various sizes, and again, calibration is done in two stages for size - one is you challenge the instrument with particles that are mono dispersed of different sizes, and you first verify that if you feed in only 5 nanometer sized particles, these size analyzer will say these are all 5 nanometer size particles and you do this for various sizes.

But then you also have to challenge the instrument to the poly disperse solution, where you have a range of particle sizes all the way from the lowest in your size range to the largest in your size range, let say from 5 to 500 nanometers, and again, the instrument has be able to show that it can sized particles as prepared in the sample solution. So, the PSL particles offer the excellent benefits that you can not only prepare a poly disperse solution but you can also prepare mono disperse solutions in a very wide size range.

PSL is a plastic material and it has light scattering, light absorption, refractive index, characteristic of a plastic particle. So, when you use PSL as your calibration standard, it does have all these advantages but let say that your sample itself is alumina, and you are using PSL to standardize or to calibrate the particle counter or particle size analyzer that you are going to use for alumina.

Clearly there is going to be an offset in the real size of the particle verses what you measure, because unless you calibrate as we discussed in the last lecture, unless you calibrate against the same material as your sample, there is always an absolute error involved, and so, the sizes that you obtain using a particle counter or particle size analyzer that is calibrated with PSL particles is known as the PSL equivalent size.

It is not the really size of the particle unless you are sample also happens to be let say plastic particles with optical characteristics that are very similar to that of PSL. But most likely it would not be, and so, the extent of deviation of your actual size to what you are measuring in a PSL calibrated instrument will depend on how far apart the optical characteristics of the two particles are.

And this is very important you keep in mind because we have a tendency to take readings that we get from these instruments and treat them as absolute values. It is never the case, very very rarely the case.

So, how do you do, let us say that you know that you are sample is predominantly ceramic. How should you calibrate the instrument? Is it know to use PSL and accept the fact that there is going to be a large deviation between the actual value and the measured value or due to try to calibrate your instrument with the different standard.

Well, next to the PSL, the next most popular standard is known as a road dust and the most popular of these is Arizona road dust. So, people have actually gone around and collected samples of various dust populations that you are getting various spaces. In turns of that, the dust population in Arizona particularly near the deserts is very homogenous in its size distribution characteristics.

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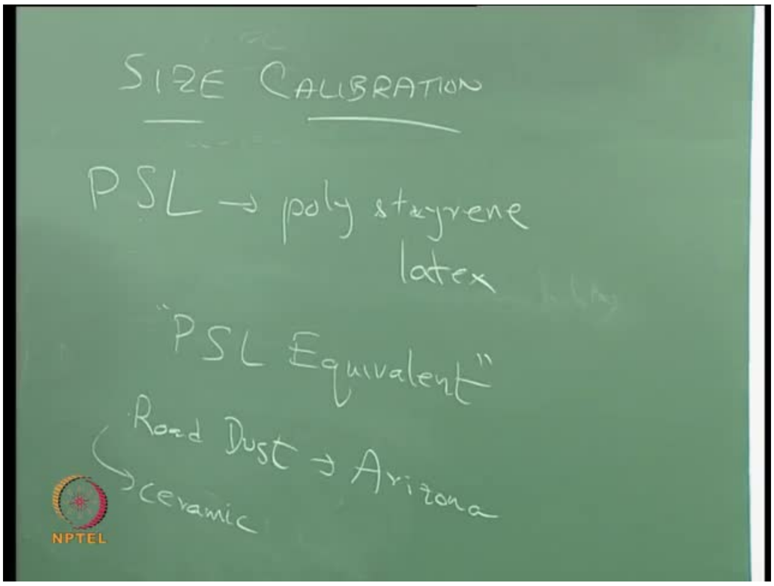

SIZE CALIBRATION

PSL → poly styrene latex

"PSL Equivalent"

Road Dust → Arizona

Ceramic

So, next well, PSL is primarily used for samples containing plastic and quasi plastic particle populations, the Arizona road dust as now emerged as a viable alternative for samples that contain predominantly metallic and silicate or alumina based constituents. So, for a something like a ceramic, you are more likely to use the road dust as your calibration standard.

The difficulty though it does not satisfy many of the properties of PSL, you cannot, for example, get it in a mono disperse form dust by nature is poly dispersed. So, you really cannot do channel by channel calibration using the road dust as your calibration standard.

So, there are some sacrifices you have to make, but overall the use of a calibration particle, that is closer in its optical properties to your actual sample thus seem preferable in many cases. Now, the difference between size calibration and count calibration is that again count calibration requires size calibration, but in addition, you also have to do a calibration for concentration and the way you do that is actually by preparing particles that are of a certain size range, but also, you prepare them to known concentrations. So, essentially, you take a liquid and put in a measured number of particles into this liquid stir it very well prepare a homogenous mixture.

And now, do not only your size analysis but also count analysis count by unit volume, for example, and you would use that data to then do simultaneously size calibration as well as counter concentration calibration of the instrument.

So, depending on whether you are using a particle size analyzer or you are using a particle counter, the calibration procedure itself is very different. In the case of a size analyzer, all you have to do is do size calibration. In the case of a particle counter which does counting by size, you have to do both size calibration as well as count calibration.

So, in many ways that the calibration and correlation of a particle counter or much more difficult than a simple particle size analyzer but the data that you get from the particle counter is very powerful; essentially, you get count verses size type of data. So, for each size channel, the particle counter will actually tell you how many particles there are per unit volume of a fluid or per unit area of a surface and this can be extremely important data in certain applications.

So, in the next lecture, we will begin our discussion of particle size distributions. How do these instruments actually characterize the size distribution or concentration distribution? As a function of size and we will look at some, there are some standard size distributions that are prevailing in nature which you always want to compare your sample size distributions to and they are very indicative of the phenomena by which this particle populations were formed. So we will look at these aspects in more detail in the next lecture. Any questions on what we have covered today? See you at the next lecture then.