Environmental Quality: Monitoring and Analysis
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Lecture No. 28
Monitoring methods for Air PM - Part 1

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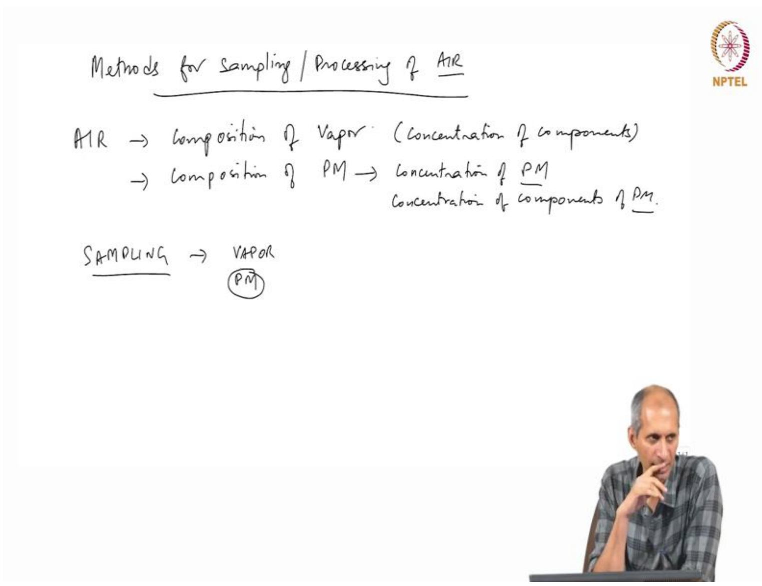

So, will continue from where we left off. So we are looking at we just finished looking at the analysis methods. So, today we will quickly go over the method for sampling and processing of air we already covered sampling of water sampling of soil processing of soil. We did not do processing of soil, sampling of soil yet we will do it today confused that also but for sampling and processing of air.

You may have 2 sampling objectives one in air you are interested in looking at the composition of the vapor which means what is the vapor phase composition concentrations in other words we are looking at concentration of different components and we are looking at composition of the PM, the particulate matter associated with air. So, in this we can look at either the concentration of PM and the composition and the concentration of components of PM.

If missing you are taking the entire particulate matter as a whole without any specific distinction, all particulate matter. And then you also make a distinction that this particulate matter is now composed of what is the composition elemental composition of the organic composition of the particulate matter itself. So, these 3 things are the objectives for air sampling typically, so, these are used for various purposes, for exposure measurements or for transport estimations and so on.

So, the first so, the sampling and analysis method as with all our cases that we have done in order to you need to have the object of first based on the object to your final analysis which instrument you are using and you backtrack, the entire trajectory of the sampling protocol is developed for that based on that. So, the sampling you have to decide whether you are sampling for vapor or PM, 2 things.

So in PM there are 2 things in vapor there is only one, the vapor phase component what we mean by vapor phase component is in this atmosphere here I am looking at the composition of benzene vapor only that is in the vapor phase, pure vapor phase as against benzene that is absorbed on particulate matters sitting on this and in running around flying around in the air. So, these 2 distinctions that we make.

So let us start with the PM because by in general when you are sampling air PM is part of the air. So if you are really looking for vapor you need to separate the PM out so that is one so we look at the PM part first and then we will go to the vapor part next to this thing.

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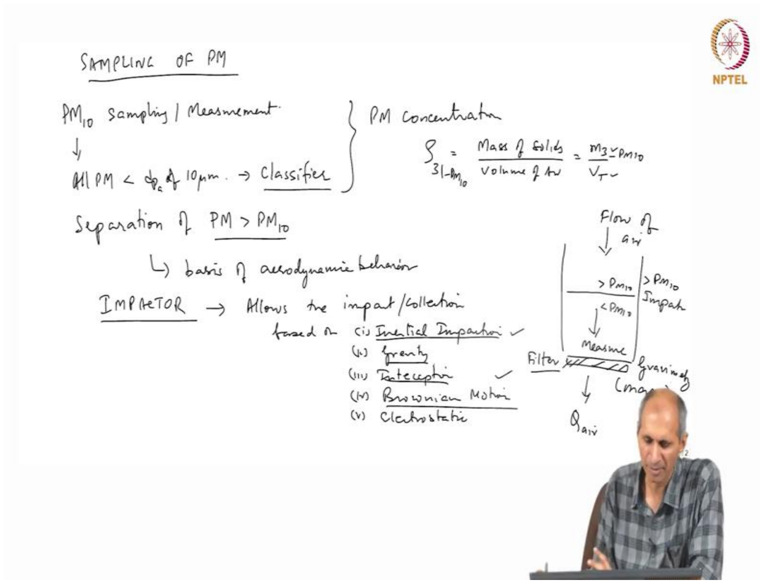

So sampling of PM there is a large set of methods in which are available now. So again, when you say sampling of PM, you have to know we know PM is classified again as PM 10, PM 2.5 and, a whole bunch of things, an ultra-fined particles and so on so you need to know what is it that you are looking for. So, let us say that you are interested in sampling PM 10. So, PM 10 sampling and measurement this is an example for what would you need to do.

The general design of PM sampling PM 10 sampling, which means that PM 10 as the definition is everything all PM with less than the aerodynamic diameter of 10 micron which means there is what is called here you are classifying you need a classifier you need to separate remove all particles above aerodynamic diameter of 10 microns and then you want to measure the rest of it. So, when you say PM concentrations, we are talking about rho 31, 3 is a solid, 1 is air flow so rho 31 is the mass of solids by volume of air is m3 divided by the V total.

V total the air that is typically we say V total equals V1 when we are doing this kind of sampling, so, we need to estimate these 2 for calculating states true for everything for vapor also, it is the same kind of definition that we are looking at so, but here, if we say PM 10, then this m3 must be PM 10 if rho 3 is PM 10 is m3 must be PM 10. So, we must find a way to separate the all particles above the PM 10 and below PM 10.

So, what is a good way of doing it a classifier or a separation of PM greater than PM 10 you are interested in collecting anything below PM 10, above PM 10 you did not care so, you have to separate it so, if any of you have used it, but those of you who have not used it or those of you who have used it also can give an opinion as to what can be done to separate. On what basis so, we are talking about aerodynamic diameter.

So, they said is on the basis of aerodynamic diameter aerodynamic behavior after particles which means that you the way the PM is defined, you use the same principles to get rid of it so, we use what is called as an impactor. And in fact that is by very simply the definition of aerodynamic behavior as we looked at from initial impaction interception mechanisms we are talking about when we define PM 10 and impactors allows the impact or collection based on initial impaction, gravity, interception, Brownian motion or electrostatic attraction or episodic forces this these 2 are the other more important.

One this is the next gravity a lot of times does not apply to these kind of situations, but it is important all of these things can happen in an open environment when we can engineer the impact in such a way that we can use one of these things. So a PM impactor so, if let us say you have an impactor. So, what will happen in impact is let us say that this is the flow of air and I have an impactor or something and what goes through the impactor.

If this is the impactor of what goes through the impactor what is retained on impactor is anything greater than PM 10 is retained here greater than PM 10 is retained here, less than PM 10 goes through and then you have to measure it. So you have various options of measuring it. One of the simplest option of measuring it is by gravimetry. Gravimetry mass measuring by the mass of it so, if you are going to measure the mass then you have to collect it.

The easiest way of collecting solid in a fluid is by using a filter. Just as what we do for total suspended solids, we are sending water, we collect all the particles we measured the filter paper before and after. So, whatever is collected on the filter paper is the mass of the particulate matter in a given volume of air. So, you have the volumetric flow rate of air and you have the mass that is collected on this.

So, now we are we have separated the components we have separated the impact of the impactor will separate whatever you want to separate and the filter collects the particles and you want to do gravimetry but you did not have to do gravimetry you can do anything else, you have another way of measuring particles you can do that also. So, the standard one of the more commonly used, this is evolving.

So, whatever I say now, may not be applicable 2 years later, so, it is always evolving depending on what you want. But the PM 10, PM 2.5 methods are fairly well established and this is we will just go over that once.

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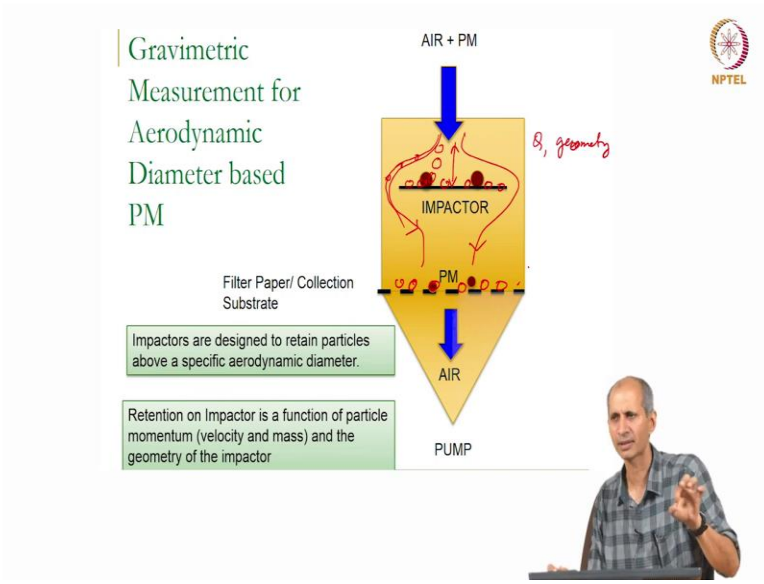

So, the impactors is typically a device that will impact particles in a flow? So one example of an impactor is something that looks like this. So go through the power point. So there is an impact as there is no segregation. So you are just doing you have a filter paper will trap all particles, you have a flow here, all particles are coming through it, and there is a filter paper air goes across there is a pump.

This is general without an impact, if I just want to take everything and put a filter paper which will trap all particles. Now, if I have an impactor there is an impactor here I put this here what will happen is particles will go some large particles will not get trapped on the impactor what essentially means is the smaller particles as you can see, tend to go around the thing. So, what we are seeing here is there is a there is a diversion, the flow goes around this impactor along with it.

This is the same principle what we talked about during the impaction smaller particles particle which have larger momentum will go will not be able to change the trajectory momentum is very high and smaller particles momentum is smaller can move around with the air. So, depending on the velocity depending on the momentum, which means it is a velocity and very specifically what we call as the stopping distance there is a stopping distance.

This is why this is how speed limits are designed for roads. It is based on stopping distance if some vehicles come right to how long does it take for you to stop? So, if you did not stop you are going collide this is impaction where if your speed is low enough, so, you can see something you can veer off or you can you can adjust your rules. So, the stopping distance is very small. So, the same can be made such that the impact is very close to the entrance or very far away from the entrance you can adjust the behavior of the particle, trajectory of the particles.

So the aerodynamic trajectory of the particle is designed and is impacted in such a way that certain size of particle we will go around. So, the impactor the factors that we are looking at is the flow rate and the geometry of the design, these 2 things are important for the design of an impact. So, you can have a PM 10 impactor you can have a PM 1 impactor you can have PM 2.5 impactor whatever. So, this is based on some mechanical solid mechanics calculation.

You can observe you need a strong basis for doing that whereas, this is not easy to first of all figure out which particle has which diameter Aerodynamic diameter design this is done using spherical particles of known density. So, you can know you know exactly on the basis of definition of aerodynamic diameter we use spherical particles to design this thing and then this is used to define PM.

So, if you know that the based on differential aerodynamic diameters, this impactor works for that particular x, particular size then it should work for anything that comes through it has an aerodynamic diameter of that size. If a PM 10 and you have tested it a spherical particles of PM

10 it should if it collects particles of any random shape and density it means that they are all PM 10 that is all it means, this is a rate we calibrated.

So, the impactors will accumulate particles will accumulate here and the rest of it will accumulate on the filter paper and then you take the filter paper and measure it so, it does this and this is a general design of an impact the impact can be anything so, this is in one of the final designs depending on the flow rate. The one of the impactors is a small plate.

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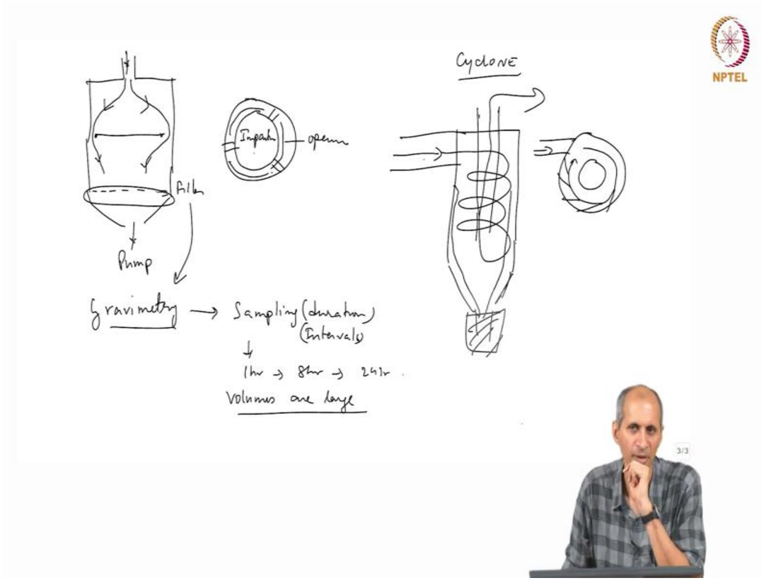

And there are so, there are there is a plate here and there is an opening in the side you can see there is a cylinder and there is a nozzle, the nozzle allows flow to come in and air moves around like this and there is a filter paper here. So, this is held in place so, if you look at the top view, it will look like this the impactor will look like this there is in fact this is an opening it is an impaction surface to look at from the top.

So the air can go all around it and in the middle, so, the size of this things will change. You can adjust the dimensions of this you can adjust distance between it sometimes what happens is because the air is going out from the side, the next impactor stage maybe something in the middle of the opening maybe in the middle, right in the middle. So, that air has to curve and go through in the center particles which cannot do that will deposit in the top outer surface, so on.

So, all kinds of possibilities exists this is one type of impact is the other type of impactor is a cyclone. Cyclone is a device where the particle, the air and the particle are allowed to impact the impaction is not a single surface it is continuously happening. So, this is based on the turning of the fluid right so, in the cyclone, the air comes in and it has to go around round and then it escapes to the center. So, if you look at it from the top, this is what is happening.

Air comes in and this is the central cylinder and outer cylinder. The air goes in and it takes it has to turn at every point it is turning particles can the tangential velocity the particles can go and hit. So, we have a larger residence time and therefore you have a larger possibility of particle deposition. So, the longer the particles, you know, you can have a larger classification of particles here you can have a lot of particles that can be removed based on this.

It is a simpler device to design and make so, cyclone is used. So, in the case of air sampling, you have industrial cyclones big huge cyclones, the size of this room are bigger, which will remove particulate matter from very large power plants and all that. But these ones you are not sampling much sampling, you are doing very small amount you are not pulling in million liters of air and all that you are, doing small amount we will come to that.

So the cyclones are very small here small as small as this sometimes very smallest size of few inches diameter, 1 inch in diameter, 2 inches in diameter, they are attached to a sampling system. An impactor this is an impact for PM 10. So, cyclone design is fairly advanced. So, you can so, the particles will get collected on the side of this thing and they will settle down here because the air that is coming has a certain you know, if you close this, if you close this part there is only one way the air can go if you go out there.

If you are if it is upright, you did not even have to keep it close you can keep it open, the air will naturally tend to go up certain escape that way unless it is dense gas which is denser gas that is denser than air then you have to worry about that. So all these are operational details. We would not get into that. So one of the constraints for doing PM measurement is the measurement itself. The filter measurement is gravimetry.

So if you have gravimetry as the measurement so what we are doing in cyclone and in fact, we are separating it. But this filter, you need to measure this filter is now undergoing gravimetric measurement, which means that a filter has to be weighed, and the amount of particles matter that is collected on it must be measured. So what is the concern for gravimetry here the same thing what we did in the TSS example? What is the constraint for gravimetry?

The minimum mass that you can measure, and you are talking about particles that are in a micron range. And we already mentioned that in that discussion, that micron range particles, the lower you keep going, they did not contribute much to mass so if you are going to do gravimetry what is the other way out? If you are doing gravimetry, you have to sample large volumes, volumes big enough so that your mass accumulation is big enough.

So, sampling times which is also called a sampling intervals can be anywhere from, you know, 1 hour or 8 hours, 24 hours or longer. And volumes are large you have very large volumes of air that you are collecting. So if you have PM is mass by volume so you have very large volumes. So if you are collecting it for shorter duration of time, you can still get a reasonably high amount of mass that you can collect that is the idea.

So because when we report PM when we report PM again objective of reporting PM what do you what will you report PM as concentration. If you are doing 8 hour sampling, it gives you an 8 hour average you are not able to say that the concentration is higher at this point is within 8 hours say I am doing from 8 o'clock in the morning to 4 in the evening, or 6 in the morning in the afternoon.

It will say that between 6 and 2 it total accumulative mass concentration is this much. It cannot do any final detail and if you are unable to do 8 hour sampling, you will do 24 hour sampling which is the entire daily average is this morning, 6 o'clock next day morning, 6 o'clock, this is what I am measuring. So, there is that information is useful for what we call us. How will we use this information if you are able to do only 24 hour average sampling, it is only as good as that.

So, when you look at standards, this is the basis for when standards are seen in CPCB's website if you did not see you have a 24 hour average standard what it means is if I am exposed to a 24 hour standard concentration and this is the possible health effect that I am so they will have if you are above the standard if the concentration of the 24 hour PM 10 value is above this, it is likely to be harmful to your health.

The reason they are doing it is that if you cannot get if you cannot get less than 24 hour averages, you cannot define a standard which is less than that. Because this is your measuring measurement tool. So if I have a tool that can measure round the clock, they say somebody is outside I say between 2 and 3 in the afternoon did not go outside, it is concentrations are very high. So just did not go outside during that time. So the time if you are outside does not matter, your average exposure is going to be very small. So your thing is going to be very small.

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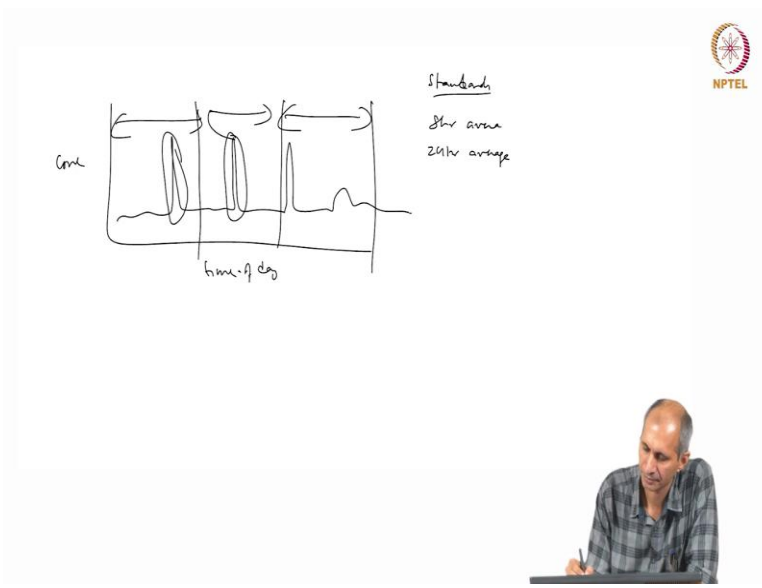

So if you look at this kind of things, you have time of the day and the concentration. So it may you have a spike, you have several spikes, and some baseline concentration. You are going to miss all of this if your sampling measurement window is the entire thing. The measurement window is this full thing you are going to miss this spikes you did not know when the spikes but the reason we these centers are reported like that are because that is that is what they have.

You cannot measure the final resolution for a very large network of samplings. So, as I said this is all will change all of this will change because every year as we go some there will be new developments in the protocols of measurement you are able to measure it for cheaper, therefore, a lot more deployment of PM sampling is done and therefore, you can go lower and lower what we would like to have is actual full real time concentration maps.

So, that you exactly have what information that you need, when are the hot times, spot times which area is highly polluted and all that so, we would like to full information so that we can use the information in whichever way you want, so these are time average samples and this standards are based on the protocols for measurement. I think that is why we see the standards will see 8 hour or 24 hour average, there is a number of different.

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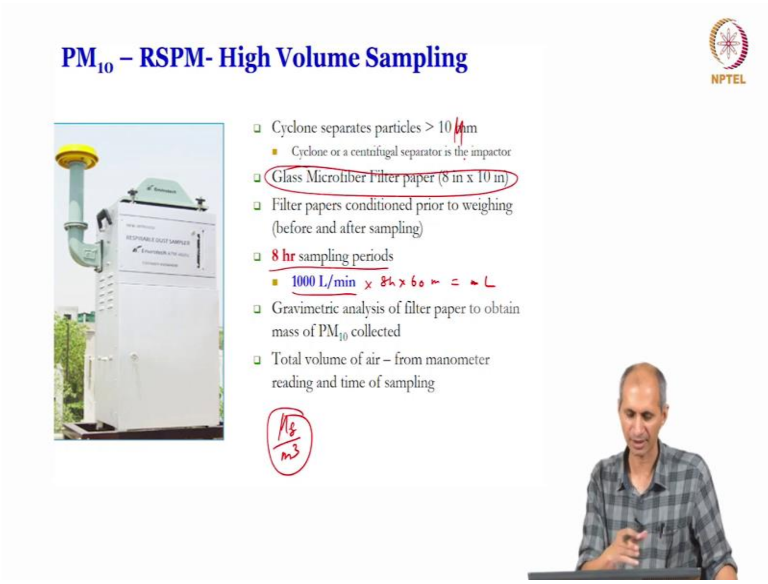

So one of the device that is used for large volume sampling, for we were looking at gravimetry. A gravimetry remains its 4 digit balance, we are looking at this kind of a balance.

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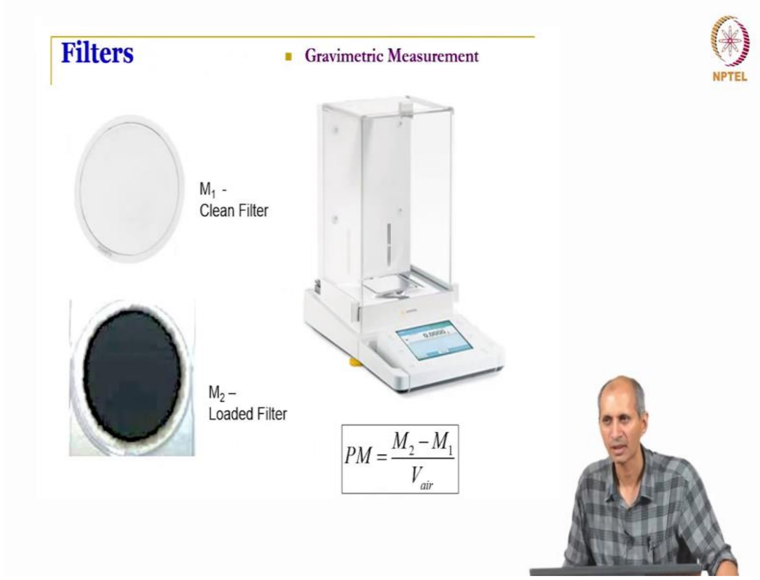

4 digit balance is very commonly available it is not very expensive, it costs anywhere between 40,000 to a lakh maybe depending on the range of what you are using for that, then it is easier for 1 measurement to be made. So one of the goals of this kind of ambient measurement is you must have as many measurements as possible will be easily accessible, people must be able to afford it. You cannot have a 60 lakh equipment to do nobody will do it.

It will be sitting there so you have to have cheaper methods of doing it. But when you have cheaper method of doing it, you are obviously going to have the loss of information. So, PM sampler is high volume sampler, you can use measurement you can measure it using a balance 4 digit balance, but then you are losing information because your sampling period is now 8 hours minimum sampling period of 8 hours in a urban area where you have a reasonable number amount of dust.

If you go to a very pristine area, you may not get anything in it, but you have to run it for 24 hours to get us get something. So, you see that the measurement protocols are all dependent on what is available for measurement and where you are measuring and so therefore, the standards are defined based on that, so this is all very interrelated and each of these will change as you get more and more research and development happening on the instrument side.

Somebody says I have an instrument which will measure PM 10, 4000 rupees. Everybody will shift to that now, because you can get wide network of these instrumentation and that is it. There is no and if you can prove that it is correct accurate, then that will be standard now, so it is in conjunction with what is available currently technology that is available currently, this is called as a high volume sampler.

Now this is a very specific company. That is why it is called as an RSPM respirable for this for the people design this based on the impact that is impacted here is a cyclone. In this particular instrument, it does not have to be a segment can be anything and it uses a large filter paper which looks like it is which is a sheet you can see that uses a glass microfiber filter to 8 by 10 inches which is like an A4 size sheet, large filter paper.

And you can sample 8 hours and 1000 liters per minutes, large volume you can imagine how much of air is going through that so the amount of particulate it collects is significant to the end of it you wait the way the filter paper before and after and you get total mass divided by total volume. So you means you have total volume. So, 1000 liters multiplied by 8 hours into 60 minutes per hour you get total volume in meter cube in liters, total volume is available here.

And then whatever is a weight that you collect on the filter paper, you divide by this number you will get concentrations typically, the concentrations of PM in air are reported as micrograms per meter cubed, all standards are recorded in this unit microgram not milligrams per liter micrograms per meter cube, very small, amount.

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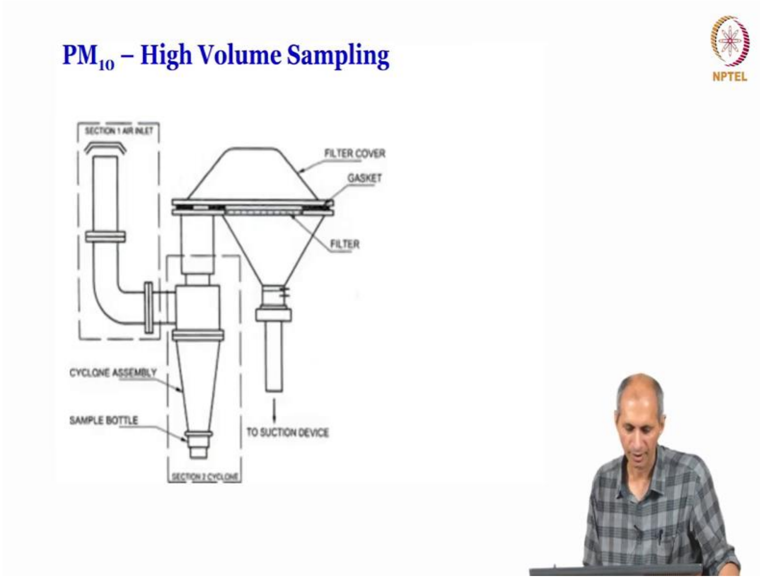

Now, this is the design of this 10 micron sorry, there is not a micron, there is a font problem it is 10 micron. So, that depends on the impactor.

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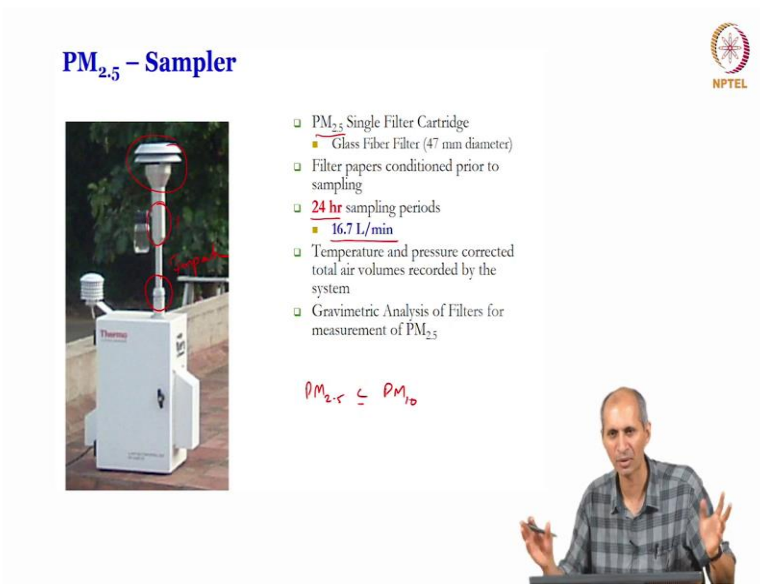

So, in this case this is the other kind of in samplers that that is use this in this case impactor is here. So, this is the air intake and the impactor is somewhere here or here impactor is in this there is a pump inside. So, this is a PM 2.5 sampler where you can see that the because of the design of the impactor the sampling is 24 hours and the flow rate is 16.7 days are related because the impact that works at a certain flow rate you have to sample for longer that is 1 second.

You are also looking at PM 2.5 the PM 2.5 is less than PM 10 then or equal to PM 10 you cannot have PM 2.5 greater than PM 10 violating must balance somewhere or you have a major error in your listing PM 10 includes PM 2.5, so, PM 2.5 is should be less than or equal to PM 10. So, therefore, whatever you collect in the lodge PM 10 impactors, PM 10 is a smaller amount, so, you have to sample for longer in order to get something useful, something that you can measure.

So, PM 2.4 all 24 hour sampling intervals measurement, so, you cannot do anything. So, you I cannot get any information on a lower timescale it is all 1 hour, 1 day average, 24 hour average only. But this is because some again depends on the objectives. The reason the way we use this data is we are looking at long timescales, we are saying what happens this year, next year in 10 years, what will happen if this industry stopped polluting, this industry starts polluting and so on.

These kind of things are all what we are discussing, when we are looking at ambient sampling air sampling, is saying this lot of particulate matter in the air. For our first question is who is causing it? What is the cost source of these pollutants and therefore, you also want to see whether this is going to last long as is an average this is not just a single event as I keeps on happening every day, this is related to the way in which the pollutant behaves in the environment. So, we only have an average value of thing that is useful sometimes.

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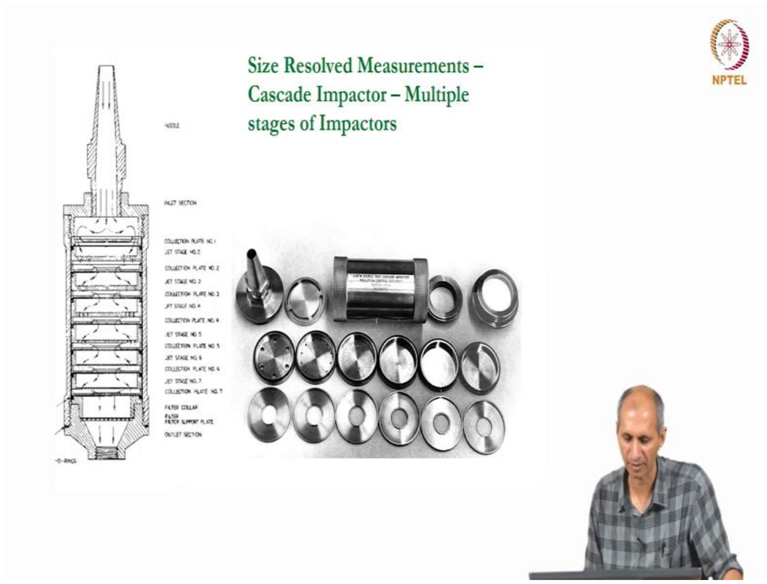

We have a next class of this extension of this when we want particle size distribution. What we are looking at in the previous 2 slides is PM 10, PM 2.51 that is it done, but what if I want a distribution, of particle sizes in different sizes how much is there in each size, then I can decide whether. So, this is what is called like a cascade impactor is just an impactor but you have multiple cast multiple impact that one place after the other.

You can see this schematic diagram here that is going in the first one, there is the first impact that goes to this one. And again, it goes through as I mentioned, it goes to the center somewhere, then it goes again, outside in centers again. So it keeps doing this in the last stage there is a filter paper. So, here I am not discarding all the intermediate stages, I am taking the intermediate stages and measuring it for much is there in each stage. So, I am collecting it so, I can as well measure it.

So, I can put some filter paper or some medium there and I can do gravimetric measurement there. It seems this is what it looks like this is a real impact as in the collection plates and the flow through. So, you can see that there are smaller and smaller significantly smaller and smaller openings in this row which allow state which changes the trajectory and it also adjust this. So, this can be one and you can have slightly larger impacts as shown on the left side figure so, this is called as a cascade impactor size result cascade impactor.

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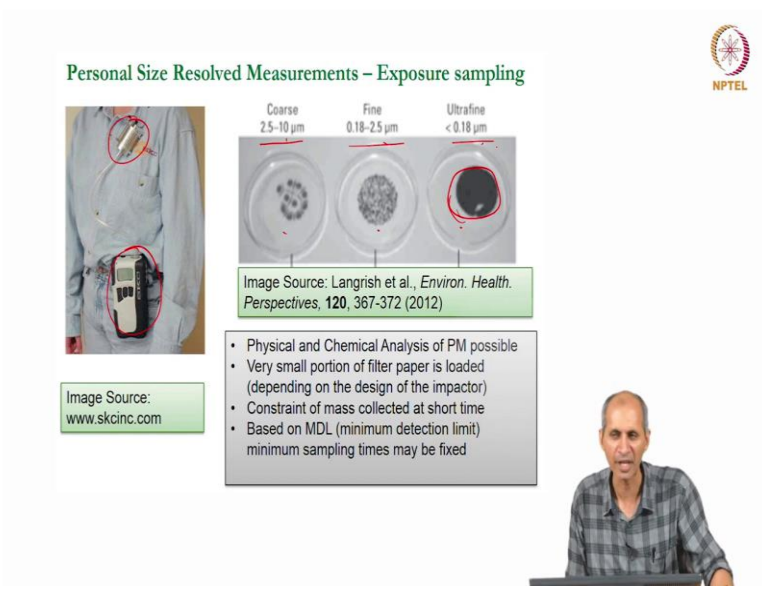

You can also have sizes or cascade impactor this is commercial equipment you can see this here is a small size as cascade impactor. People put this and work from for 5 hours they will work and is a pump here you can see there is a pump and it will give you the filters in each stage will look like this and you can coarsely define based on the impaction design you can say 2.5 to 10 microns, 0.18 to 2.5 microns and less than 0.18 microns.

So, you can have some classification broad classifications and you can see that as a size keeps going down and the amount of particles also is going down very thick are here from here is very large. So, this indicates that very large amount is less than 0.18 microns, but you cannot classify it further it all gets stuck on the filter paper. This depends on where you are for some distributions depends on distribution of particles in that area.

It will always not look like this it will look the reverse sometimes large particles will be very big and smaller particles will be very small and that gives you an indication as to what is the nature of particles, it seems a very painful thing to do especially when I have so is this all the instruments that is used.

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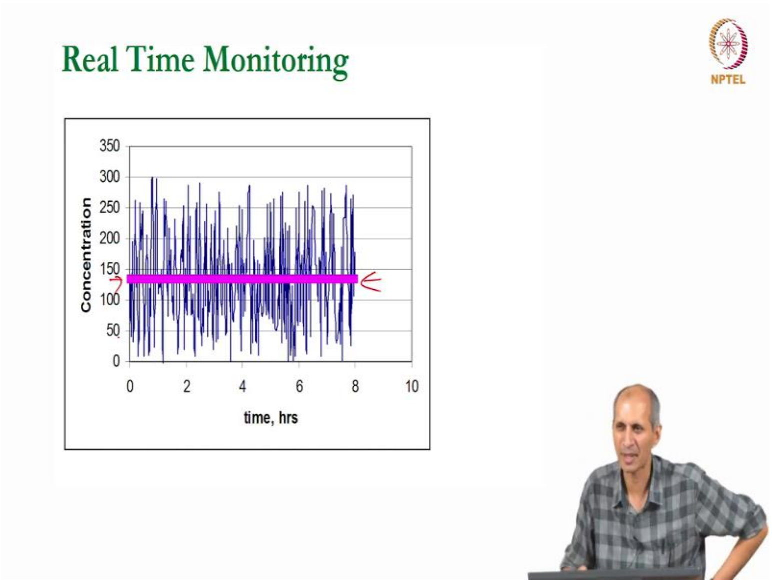

In this is a problem so when you are a regulatory agency you really like to know real time information, you would like to know what is going on real time so that you can focus your energies on fixing where the problem is which is a biggest source of pollution. And, like in investigations is really like, you know, proper investigation or you are looking for clues and you are kind of connecting with what is the cause of these things.

So the blue line here indicates the real time data and the pink line indicates average, so I have an 8 hour average I am I have this concentration, 8 hour average, so 125, 130 or something, but I can see that throughout the day, the concentration is going up to 300 and coming back down to 50 or 0, all the way this is possible. So people are looking for real time monitoring all the time.

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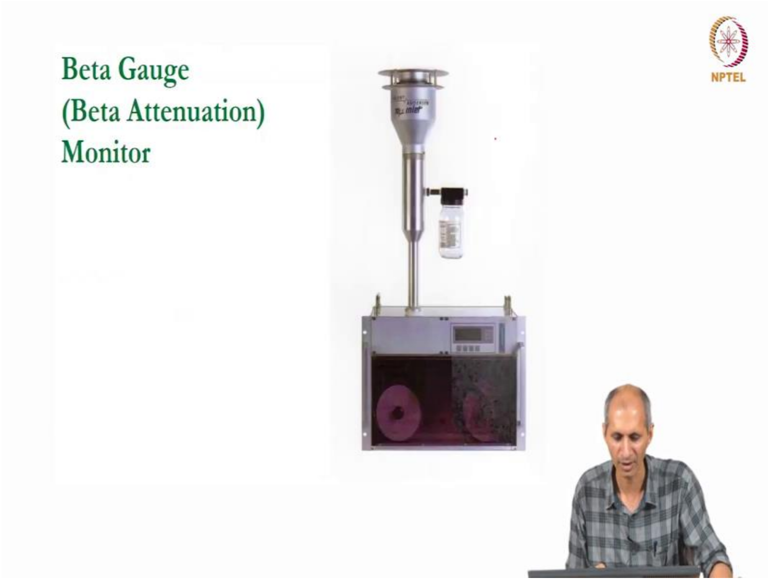

So there are a lot of instruments people are trying to develop do real time monitoring. And one of the things that people do in the CPCB's monitoring station in regulatory agencies is to do one of them is called a Beta Gauge monitor.

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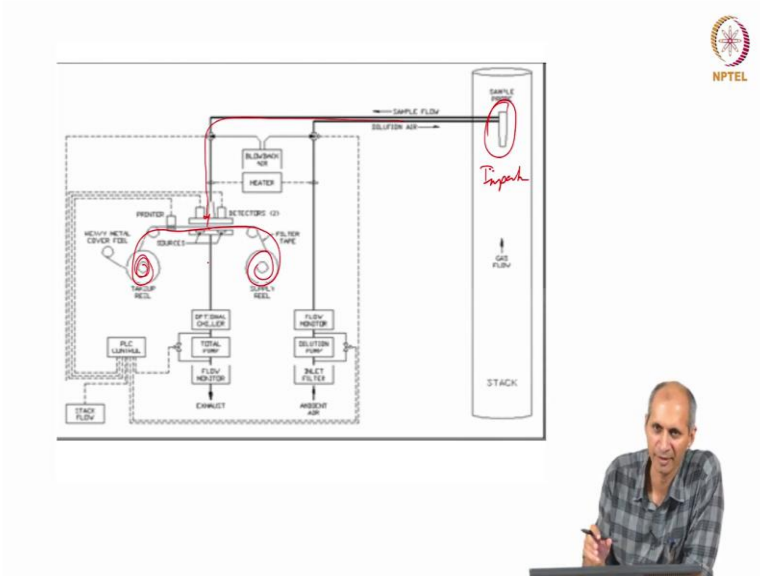

Beta Gauge monitor is a very difficult slide to read, but basically what it what it looks like is this there is a roll of filter paper, the filter paper rolling here, there is a sample in inlet sample, it goes in sample goes in through here and deposits on the filter.

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So, there is a small amount. So, for a certain period of time there is some deposition and then the sample moves to a an optical detector, the optical detector send some light or some wavelength and it measures what is the difference change in the attenuation in the signal attenuates which attenuates more if there are more particles, I can read less if it is like absorption what we saw scattering absorption.

Basically it will look at transmission and it will say if a certain amount of if there is a lot of loss in transmission, it means there are a lot more particles that is all simple as that. So, you have to calibrate it against that the particle mass is calculated against the transmission and then you say if this much is a loss in transmission, I am assuming that this is a particle because you are already classifying it here, you are classifying it, you are removing all you are doing PM 10, is impactor here.

So, what is coming through is PM 10. So, you can measure PM 10 in real time, and depending on the sensitivity of the transmission loss, I have a minimum sampling time I will wait there for 10 minutes, 20 minutes, half an hour, 45 minutes, whatever time it takes for me to collect enough material that will give me sufficient minimum detection it has to be determined and the sampling time estimator.

So, you see all of these things are important in the design of equipment for real time analysis. So this is one thing that is used in is, there is another equipment class of micro balance tapered element oscillating micro balance, which looks basically it allows for the deposition of particles on the tip, which will vibrate which will oscillate, and, based on that they will calculate what is the amount? So this also is it is every reused every accumulator which means that the change will incrementally change.

So, it is like putting a small thin film and particles keep depositing and the thin film will bend and the more bending which means that more particles. So, you can incrementally say 5 minutes and bending 5 minutes this much then bending so you can get distribution as long as you are able to detect that change. In this case, it is changing the detection of the vibration or some force, the force measurement or some such thing. They are all very sophisticated instruments. You can I can imagine that this is going to be more expensive than your high volume for 4 digit balance obviously.

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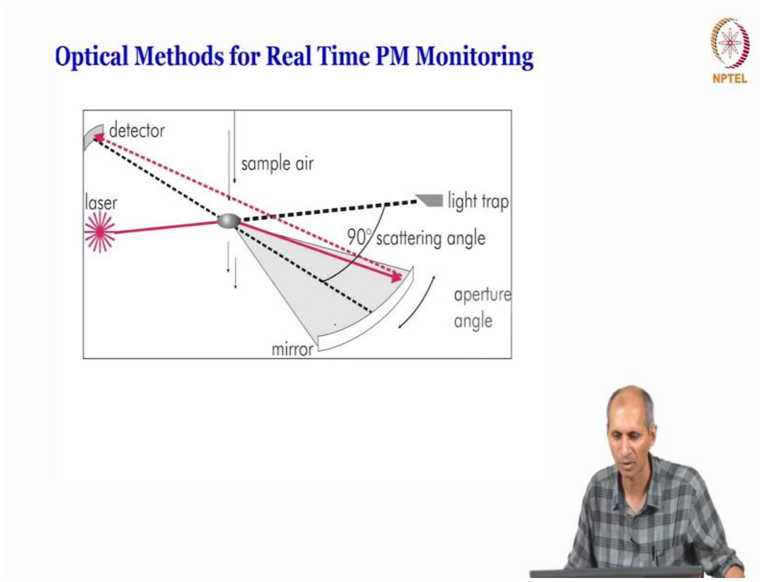

There are other methods of doing real time analysis. I am going to ask a question at the end of this discussion and you have to be prepared for that. There are optical methods which is there is a laser and it is based on scattering principle there is a particle light hits it, it scatters and is based on the scattering law, the amount of scattering an angular scattering depends on the size of the particle. So, different detectors are kept here.

In a full design, there are a lot of detectors that are kept at different angles and you can find out which is the, what is the size based on the scattering angle and you can also measure the composition concentration of it, count the number of particles.

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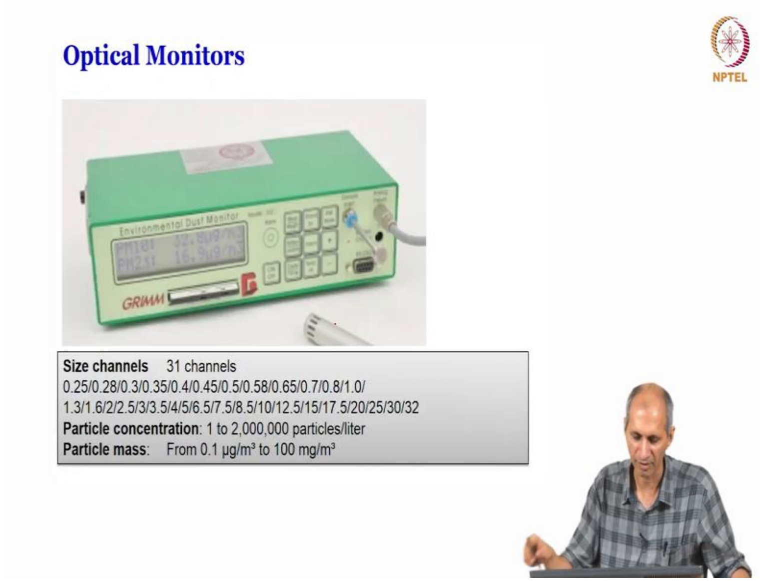

The real time monitor, this will give you data. Very good data will give you a real time data because it is measuring it as it is going through particles are going in and scattering is happening continuously lasers hitting it and you are getting numbers you will get numbers like this and there is a filter at the end of the system which will collect some amount.

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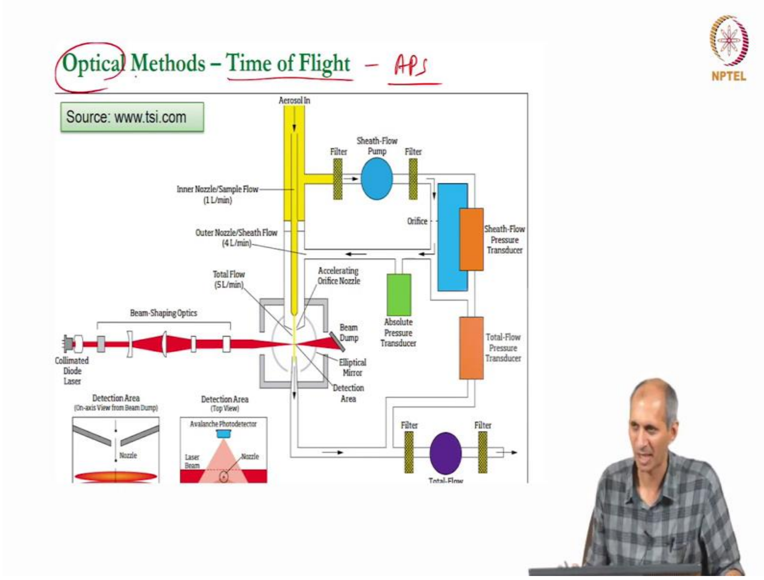

This is a next level of optical instrument. So, this is based on scattering this one there is another instrument which is based on what is called time of flight. This is called as an aerodynamic particle sizer. And as the name suggests this exactly does what the aerodynamic diameter definition is it takes the particle and it trudged finds out what is the momentum of the particle, how fast it is moving a certain size.

And then based on that it calculates, what is the size of the particle? So, there are 2 lasers it calculates how much time it takes for a particle go from one place to another place, and it is a very sophisticated equipment called as APS, this is not an optical method. This is aerodynamic method.

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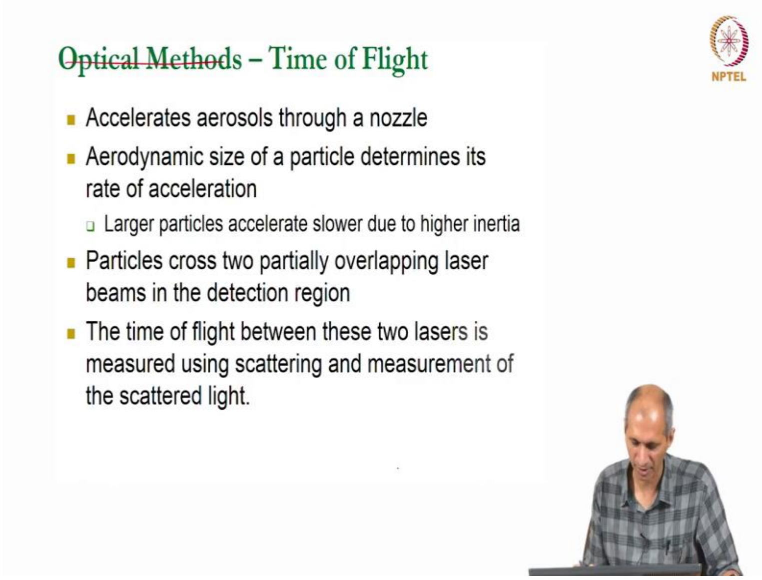

This is incorrect, aerodynamic method. Now, you have these instruments in real time. Why would anybody want to use a PM based gravimetric measurement when you have these available you are getting real time data you are getting, you know, without much thing, no processing required. It is very easy for students to use it, they will take this thing, put it there and numbers are coming and you just have to plug in a USB drive or something and get the data that is it done.

Nothing more no work involved. There you have to take filter paper rate, go and measure it come after 8 hours, take it out and you are getting 8 hour average loss of information or in a cascading packer you are taking. Why would you want to still do that? One is a very obvious reason. What is obvious reasons? Cost one say cost is there, but you still want to do it **"Professor – student conversation starts"** What is the second reason why you missed we want to do it for a composition **"Professor – student conversation ends".**

So sometimes you want chemical composition, and you are getting a lot of material. So you are, again, you are looking at composition that composition will give you a lot of clues to where it is coming from just getting mass distribution is not enough multiple sources may be giving it you forget size distribution, it may not be just enough. So people are always trying to find out the cheapest method of doing it.

What we call a source apportionment, we have source of water and you can do source apportionment as long as you get a very specific signal for a source. But sometimes it is mixed signals, you did not know how to resolve signals. One way of resolving these signals is by using composition, chemical composition. If you have enough information in size distribution that may be enough for you to make source apportionment.

That is fine, that is good but if you want complete information, you need to get composition which means you need actual physical mass. That is just wondering the second disclaimer here is this optical method is not measuring aerodynamic diameter, this is measuring a scattering diameter. So, it is a different diameter than what we define as PM 10 it may be the same for some particles, but it is likely that it is not.

So, you have to be very careful when you are reporting this as PM 10 versus something else you have to make sure that this is there is a correlation between this and that so, the only way to do a correlation is you do PM 10 using the APS this is this will report the aerodynamic diameter. You can put this versus this you can see this is this instrument is much cheaper when this instrument obviously you can see the amount of electronics and amount of testing involved in it.

So, this is always going to be the challenge and currently we are a lot of groups working on trying to get cheap instrumentation. Because, one of our goals in fate and transport, as we will see, the next is to have a wide distribution of measurement. We want atmospheric measurements, somebody will give you some number and does not we did not know what it means, as you saw in the newspaper. We did not know what it means I say composition is this much what does it mean? I have no idea.

Is it a composition that is arising out of one specific event that happened this afternoon? Or is it a continuous thing? Or it is periodic? We did not know so, it is all of these are gives information of what is happening in the system. And the system is huge it can be system can be city of Chennai, it could be system can be city of Chennai and the surrounding 50 kilometers. It can be the entire state of Tamil Nadu and the Bay of Bengal it can be the entire southern subcontinent.

And the timescales are varying and all that size. It is the case with Delhi we did not know what is the system boundary there because of these kind of things. So the full information of PM will give a lot of close to where what the problem could be.

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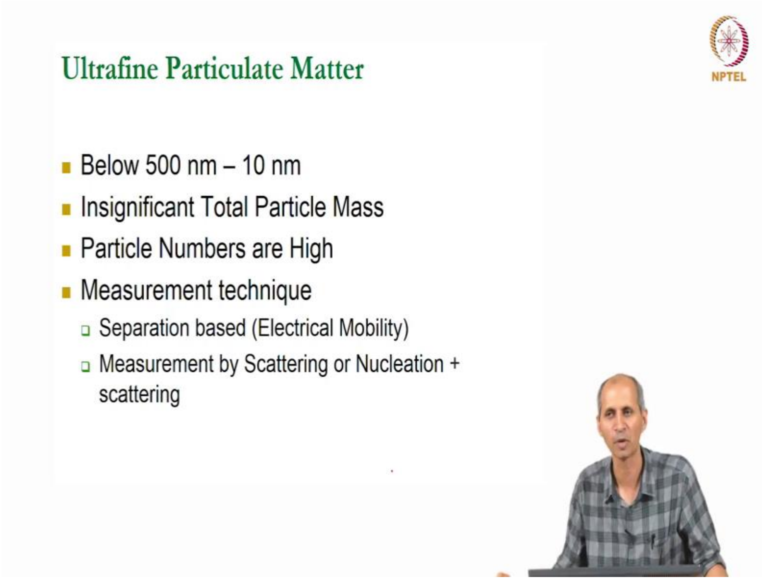

So, there are further something called ultra-fine particulate matter these are particulate matter which are below it typically is 300 nanometers and below 500 nanometers in that size range. The reason this is important is a lot of emission coming from vehicles, diesel analyzing particulate matter are in this size range, it is known very well known that then it is if you look at the particle size distribution we have seen that there is something called as a nucleation condensation.

And nucleation range which starts from the lower end and the higher end of particles are mainly from mechanical breaking, breakage, erosion that can also because they are originating from larger particles this is originating from vapor. So, originating from vapor is compressions are all like that there is a vapor phase at very high temperature it condenses forms of particles thermodynamically from the smallest size possible.

So that will be a sphere very small nanoparticle and condensation occurs and the particle grows in size depending on how much exposure is there in the system. So these are all small particles nanoparticles and there is a general theory. So if you look at the trend of PM that is has a health effect. Earlier they had no idea they are all PM is not that then they said PM 10 because PM 10 goes into the nose then is at PM 10 does not go into the lungs it stays somewhere near the nose and throat PM 2.5 goes into nose.

Now the theory is further down we are going further down you are already in the nanometer nanoparticle range is few 100 nanoparticles, very difficult to measure. So how do you measure nanoparticle nanoparticles you cannot do gravimetry. You have to collect millions and millions of particles and still you were not sure whether you are collecting that size range. Classification is very difficult because classification by aerodynamic method is difficult. Because that is based on momentum and the mass of particle is now gone so much that you cannot use momentum as classified anymore. So, people use what is called us electrical mobility.

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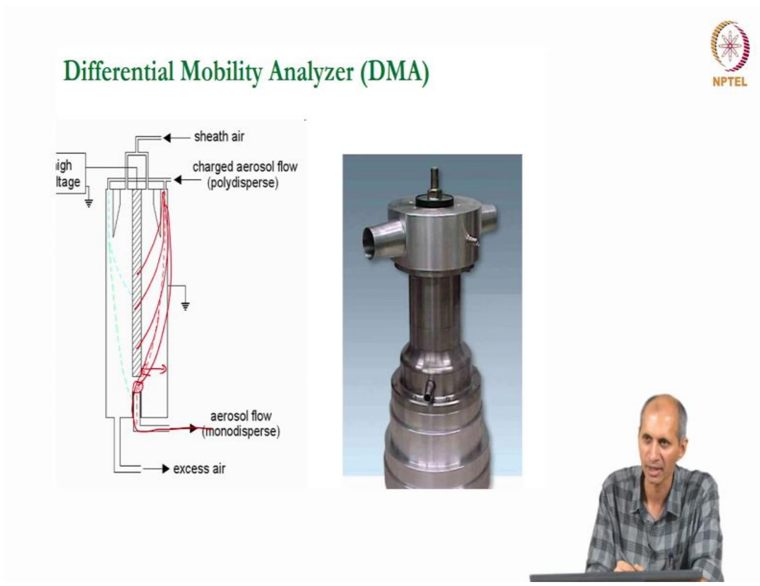

So electrical mobility, and the instrument that is used to make is called as a differential mobility. So we will just very briefly look at it I will take few more minutes we will be done. And this instrument, what it does is it allows it charges all the particles coming in. But depending on the size of the particles, different charges accumulate on particles, and then there is a flow and there is a potential difference that is placed across these 2, there is this is a concentric cylinder in the center there is a there is like a cylinder small cylinder and outer there is a bigger cylinder.

Between this there is a potential difference. This potential difference will pull particles of a certain charge towards the end plus is also moving so based on the electrical charge, and the flow particle also has an aerodynamic behavior there is a resultant trajectory as seen by this red and green dots in this picture here. So, for a particular size of particle at a particular voltage, you can expect one particular directory, if you change of this directory will change.

So, what is in this instrument has an opening here, very small opening particles of that trajectory which correspond to that will go into this opening and be taken out of the stream rest of it will go out. So, you are separate it is like doing mass spectrometry, you are only giving that one particular size tag and you are, you are allowing one of them to go through the rest of them, you are freaking out. So, you are separating it like that.

So you are changing the voltage from one value to another value. So different particles have different trajectories at different times, and it can throw the entire thing. You only want one particle size you can fix the voltage and only that particle size. We will go through but if you want the full scan like the mass spectrometer you have changed the voltage and the under trajectory will keep changing.

Whatever this particle will be here next here is the voltage will be your next here and next then it will go here then it will go through so on all particles go through this depending on what is your design, but we still did not have a method of measuring it.

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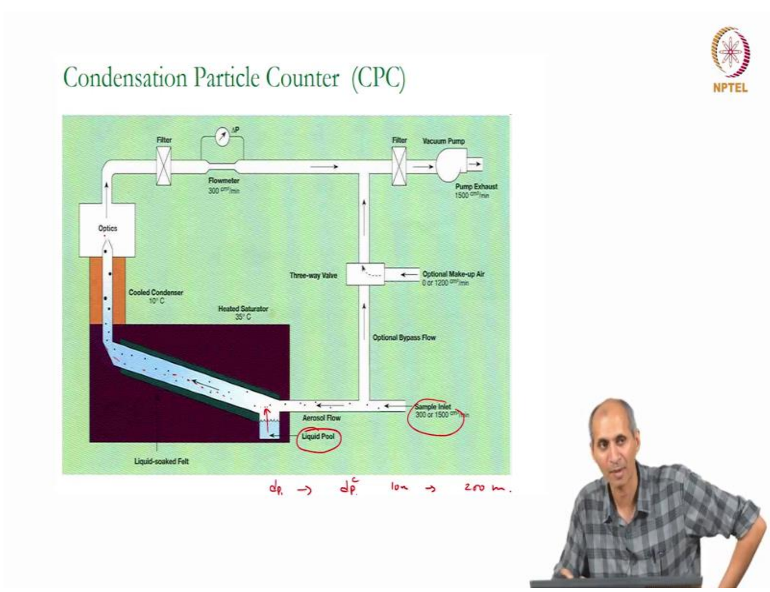

So, that method of measurement called as a condensation particle counter this small nanoparticles you did not have a way of counting it yet. So, but you will know how to count particles that are in the range of sub about 0.3 microns 0.4 microns. So, this is using the scattering instrument, which we already saw that the limited there is about point 3.2 microns. So, you allow the nanoparticle to grow to that size.

How do you allow it to grow this is a particle is coming from here, the sample inlet particles are coming in here, and it is exposed to a saturated environment of some vapor? So, there is a liquid, here and this is evaporating and it is condensing on the particle you can see this particle has a residence time in this region and it grows it grows to a certain size. So, particle of dp 1 grows to a particle of dp c let us say so, a particle of 10 nanometers will grow to say about 200 nanometers, a particle of 20 nanometers may grow to 300 nanometers and so on.

So, there is a correlation between what is coming in and what is going out because the rest of it is fixed so based on that you can calculate the particle size distribution and back calculate, what is the particle size that is coming through.

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So, very complicated instrument, the entire thing is called as a scanning mobility particle size or SMPS very expensive instrument cost around 50 lakhs, 60 lakhs as you can imagine, and what is used a lot in trying to understand what is the distribution of particles all the way from 10 nanometers up to 10 microns, you can do the entire thing in 1 sweep.

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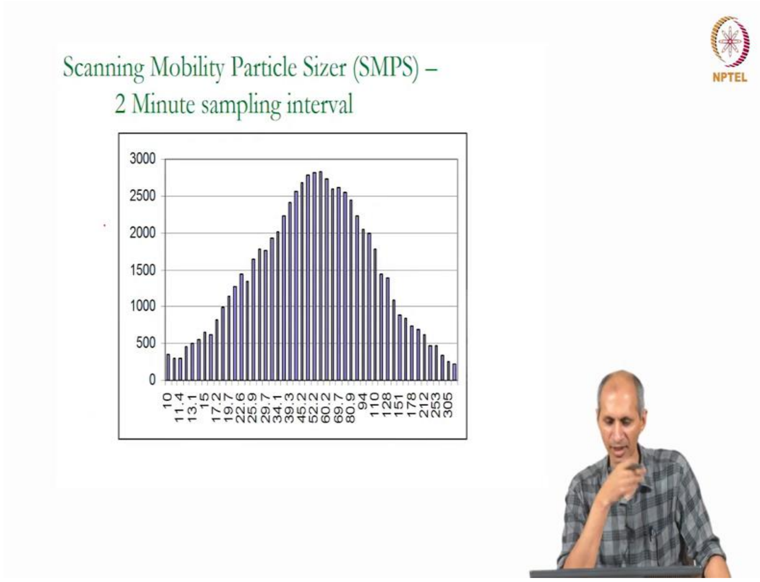

You will get data that looks like this you will get all kinds of things, so we will continue the rest of it tomorrow looking at chemical analysis and physical analysis.