Particle Characterization

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Module No. # 12
Lecture No. # 35
Practical Relevance of Particle Characterization: Cleanrooms

Welcome to the thirty-fifth lecture in our Particle Characterization course. In the last lecture, we began a discussion of filtration technology Filtration is the discipline that involves many aspects of particle characteristics, in particular size and shape, and we looked at several examples of different kinds of filters and the filtration efficiency, in terms of its relationship to particle properties, in particular size and shape.

Today, we are going to continue the discussion of particle control technologies. A good example of that is a clean room. A clean room is essentially an isolated environment, in which the level of contaminants in the air is controlled in an active manner. So, these contaminants could be particulate in nature or they could be chemical in nature as well. And essentially, what we try to do is within this enclosure, which is well sealed so that there is no leakage of outside air into this room, and the only passage for the air to enter the room is directed through filters. As we were talking about in the last class, there are HEPA and ULPA filters that are used to treat the incoming air just before it enters the clean room enclosure, and the design ensures that is the only way outside air can enter the clean room.

So in principle, you can control the cleanliness of this clean room facility by ensuring that air only enters through one passage and that passage is completely filtered to remove unwanted particles of various size ranges. And you can also use chemical filters, for example, if you use activated charcoal as a filter, it will remove all organic materials. If you use a bicarbonate filter, it will remove the inorganic materials. But in particular, we are going to focus on particulate filtration.

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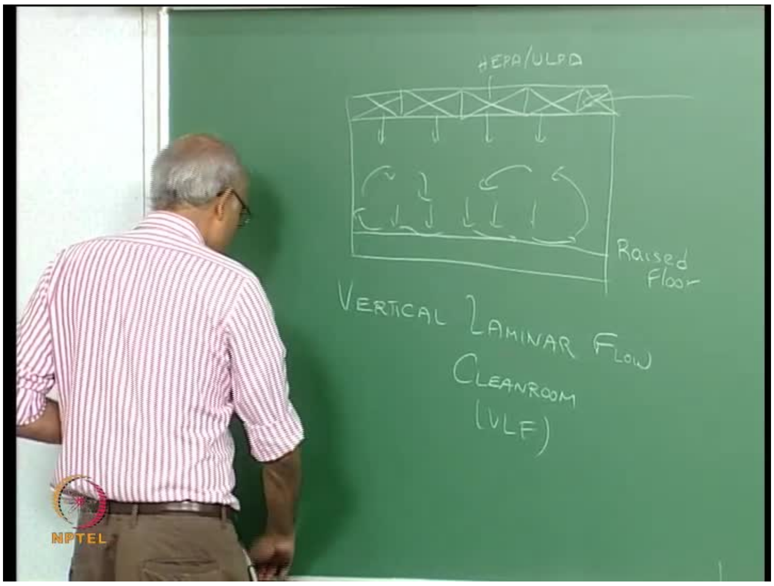

Now, a clean room if you want to sketch it, it is essentially looks like a box. Now, this is a sealing and it is essentially has a false floor, it is called a raised floor. The sealing also has a duct in which the filters are placed. So, in this area you will have coverage through filters and the incoming air will essentially be forced through these filters, and then make to exit into the cleanroom. So, this is where your HEPA filters and ULPA filters will be located.

Now, the most popular design for the cleanroom is what is known as a vertical laminar flow cleanroom. In a vertical laminar flow cleanroom, it is also known as a VLF cleanroom, the air enters the room at the top through filters that are located on the sealing, it is then directed into the room in a unidirectional manner, the flow, air flow is controlled in such a way that all the velocity is vertically down. Now, the problem with that approach is the air flow will keep coming down, but then when it reach the floor, what is going to happen. Essentially, you are going to get stagnation flow. So, you are going to start getting some recirculation, convection roles and all that, which is not good. Because in a cleanroom, what you want to avoid is such phenomena as natural convective flows, convection roles and so on, because they extent the resonance time of particles inside the cleanroom. And the longer the resonance time of particles, the greater the probability that they will deposit on critical surfaces and cause yield loses and reliability failures and so on.

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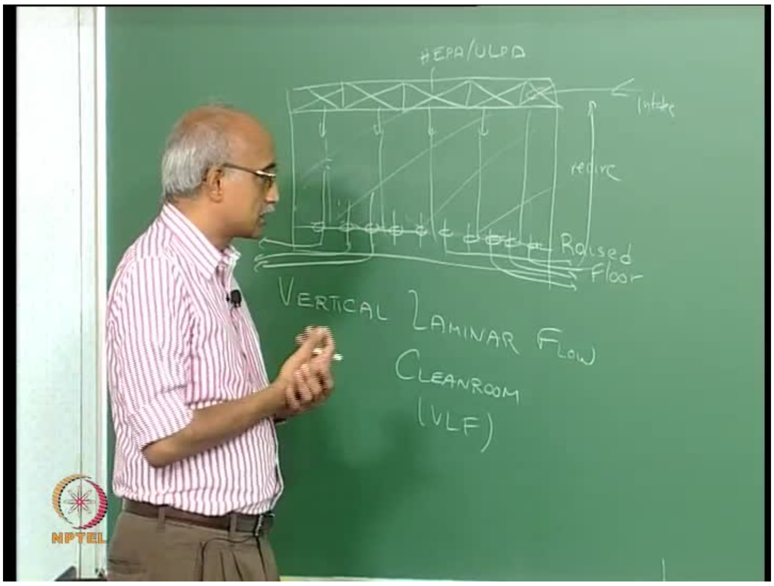

So, in order to avoid this, what you do is essentially have a false floor or a raised floor, which has holes in it. So, this air is drawn through these holes and then it is exhausted out of this false floor. So, all the air is essentially made to leave in this fashion.

So, again you do half stagnation flow, but now it is it is below the critical manufacturing location. Because all the manufacturing operations are only taking place in this area. So, within this area, the flow remains essentially vertical and laminar. So, this is the ideal configuration, in a cleanroom you do not want turbulence to happen, you want all the air flow to be at high velocity and directed in such a way that it takes particles that are located inside the cleanroom, and as quickly as possible purges them out of the cleanroom. So, this is kind of the overall setup that you want to have.

Now, what are some of the challenges in operating such a cleanroom? This air that you are venting out, if you can continuously keep exhausting it to the atmosphere, that will provide the best cleanliness. Because you keep bringing in clean air, it gets dirty inside the room and then you went it out.

The problem is the energy consumption air flow usage is very high. So, to operate a cleanroom in this fashion, may provide the best controls on the levels of particles, but it is also the most expensive to operate a cleanroom. So, instead what you do is, you take some fraction of this outflow and recycle it. So, you build in a continuous recycle loop which minimizes the total air handling that your filter systems have to do.

So, it basically reduces your intake air, if this is your intake and this is your recirc, the total air flow into the cleanroom is the intake air, or it is also known as the makeup air, plus the re-circulated air. So, clearly the recycling strategy has certain benefits in terms of cost controls, but from a particle control view point it is obviously, not as good unless the external environment is much dirtier than the interior environment. For example, if you have a cleanroom operating in the middle of an urban area, where this lot of automobile exhaust and so on, it is possible that the outside air is much dirtier than the inside air, where the process is going on. In that case, actually this will give you both benefits, it will give you a lower cost and it will also give you a cleaner facility, because you are minimizing the amount of air that you are taking in from the outside.

So, this ratio of recirculation volume to makeup volume or intake volume of air is a very critical parameter, and it needs to be optimized for every cleanroom application you have. So in order to do that, what do you do first? You have to develop a model for the cleanroom. So, you have do CFT modeling to obtain a predictive description of how the flow field in this environment will behave. If you look at this, it is a classical fluid dynamic problem, you have essentially a fixed control volume, which is a cleanroom that material is entering and leaving. And it is essentially a two phase flow, you have the gas phase, in this case air, and you have entrained particles in it.

Now, depending on the size of the particle some of them you may treat as single phase, but as the size of the particles becomes larger, you have to treat it as a multiphase problem. So, it is kind of a combined single phase multiphase problem. And there are classical methods of solving this problem. You can essentially write down the conservation equations, for example, you can write the total mass conservation assuming density is constant, you can write it as del u by del x plus del v by del y plus del w by del z equal to 0; where these are the velocity components in the different x, y and z directions.

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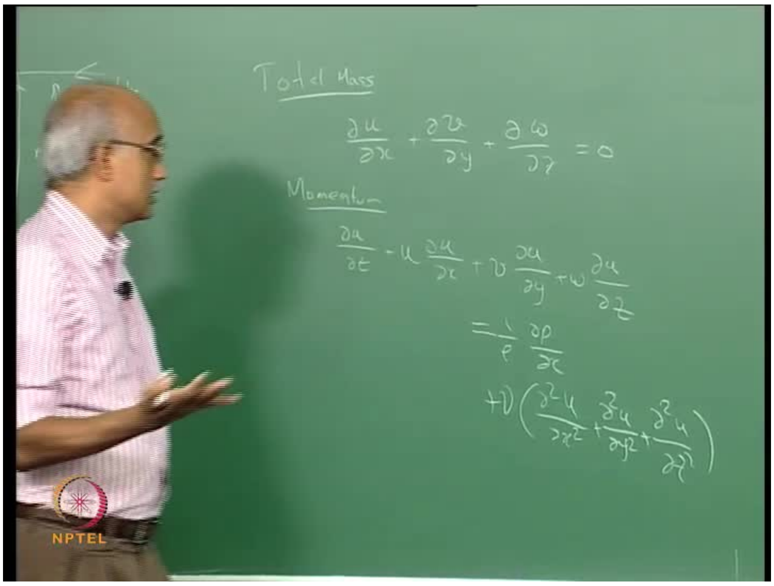

So, you can actually do a very rigorous 3D model of this cleanroom, and then you would write the momentum conservation equation as; del u by del t plus u del u by del x plus v del u by del y plus w del u by del z equals 1 over rho del p by del x plus nu times del squared u by del x squared plus del squared u by plus del squared u by del z squared.

So, classic equations, momentum conservation equations, Navier-Stokes equations can be written. And also if this is a non-isothermal cleanroom, where there are significant temperature differences, you also have to write the accompanying energy conservation equation, and then solve everything simultaneously, you have to apply the appropriate initial conditions and boundary conditions. For example, the initial condition for such a facility may be that, the starting point of a cleanroom is where essentially there is no source of particles inside the cleanroom and all you have is air entering and air leaving. So, you can look at the time 0 point as a steady state, where essentially there is no contamination source in the cleanroom. The boundary conditions, we will have to impose for the various situations. For example, along the walls you can say, no slip boundary condition, which is a Dirichlet type of boundary condition. But near the flow paths, the intake path as well as the out flow path, you may want to impose a Neumann type of boundary condition, which says that the gradient is 0, del v by del x or del v by del y equal to 0.

So, by applying the appropriate initial and boundary conditions, you can essentially setup the model, solve it numerically using finite difference approximation. And you can actually get a very precise description of how the flow field will look like, the velocity distribution, and you can also predict how the particle concentration distribution will look like inside the cleanroom.

And in fact, we have done that exercise in our lab. We have developed a model for the cleanroom in the department of the electrical engineering, and we have actually matched our predictions to particle counts that we take with an air bond particle counter and the two match pretty well. So, it is certainly possible to deal with this problem in a mathematically rigorous fashion. But the limitation to that is that, the model that you develop in this fashion obviously, it is a very simple model, in the sense that it does not account for the various complexities that can enter.

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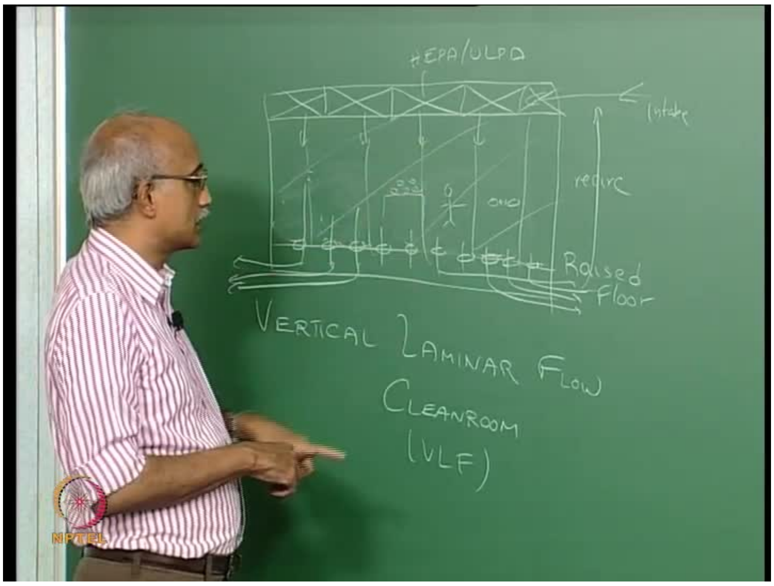

I mean the assumption here is, it is an empty room, but that is not true. I mean any cleanroom in which a manufacturing process is running, it is going to have all kinds of thing in it. It is going to have work stations, on which you are going to have some parts, that are sitting there. It is going to have people, again people may be standing, walking, moving around. It may have a various parts storage locations, people may be wearing garments, gloves. But most importantly, this person is going to be doing something. So, there may be two parts that are getting assembled together. So, when you assemble anything you generate particles.

So, all of these certainties really cannot be captured in a very rigorous model. Well you can, but then the complexity of the model will become so high that, you know, the CFT code may take forever to run a single simulation. So, it becomes somewhat useless. So instead, what you can choose to do is, develop a simpler model for a cleanroom. For example, you can assume that the cleanroom is essentially well mixed so that, particle concentrations everywhere inside the cleanroom are uniform.

Now, that might actually appear to be in conflict with the vertical laminar flow type of a model, because, I mean by definition this says that the contamination level particle levels are going to be lowest near the filters and they are going to keep increasing as the air flows down towards the floor. So, it is a questionable assumption, but it will make the model easier to deal with.

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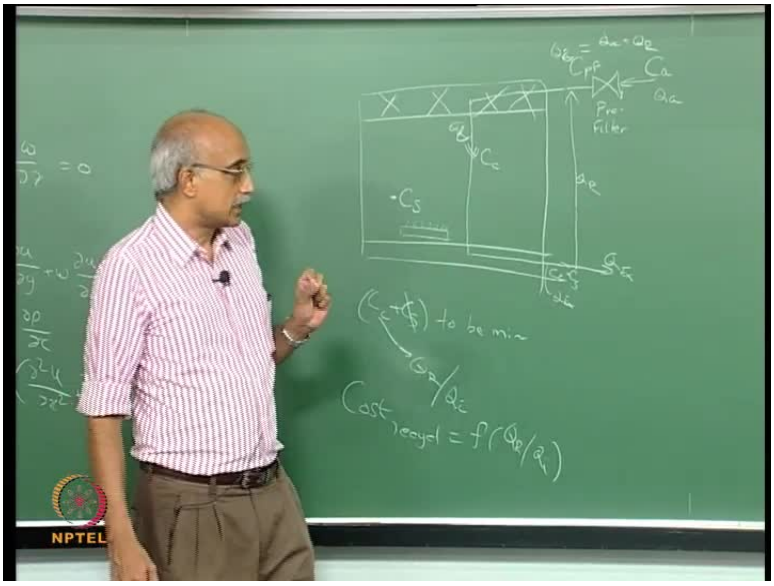

The other assumption you could make is all the flow rates are essentially, in steady state, constant flow rates. You can also assume that concentrations are not varying with time. So, essentially you can simulate a quasi-steady approximation to the operation of a cleanroom. Now when you do that, the picture is going to look like this. Again you have the cleanroom and you have particles coming in, now there is usually a pre-filter, as we discussed in the last class, the pre-filter is likely to be a fibrous filter; whereas, the HEPA and ULPA filters here are likely to be membrane filters. And then you have the bottom, so the flow comes in like this, goes to the filter bed, enters the cleanroom and gets exhausted outside. And this is basically the flow path that the air stream will follow. So, all entering particles will also follow the same pattern.

Now, let us say that some part of this is now being recycled and going over there. So, how do you develop a simple steady state model for this? What you are interested in is, predicting the steady state particle concentration inside the cleanroom. So, let us say that what immerges through these filters is a uniform concentration of particles inside the cleanroom, let us call that C c. So, this is the uniform steady state concentration of particles inside the cleanroom.

Now, in the ambient air you are going to have some concentration of particles, let us call that some C a. Now, the pre-filter is going to remove some percentage of that and so, you will have a, let us call that C PF, which is the concentration of particles as it comes out of the pre-filter. And then, once it goes through the final filter in the cleanroom, it immerges with a concentration in C c. C c is now the concentration of particles that is uniformly distributed in the cleanroom, which means that in the outlet stream also the particle concentration is going to be C c, it is like a well stirred reactor. So, the exit concentration will be the same as the concentration of particles inside, if you want to look at this cleanroom as a reactor, it is probably a good analogy.

Now, the other concentration that we have to be aware of, I mean what are we missing here? Is this a full picture? Or is that a term that we are missing? Just think about particles, what is the basic assumptions here? The basic assumption is all the particles are only coming from outside, but we know that is not true, because particles are also getting generated inside the cleanroom.

So, either source term, let us called that some C s. So, there is a source of particles inside the cleanroom, which is contributing to the total level of particles. If that is the case, then clearly this is not the concentration here right, it should be C c plus C s. So, that is the concentration of particles in the outlet stream from this cleanroom.

Any other sources or sinks for particles that we should be aware of? Well, there will always be losses due to sinks at the walls, for example. But, let us say that for the time being we ignore all that, let us say that all particles are entering being generated and then being exhausted.

Now, the other parameter that we need to know in order to do a mass balance on this is flow rates. So, let us say that there is some flow rate Q a that is entering in the pre-filter and the flow rate does not have to change, as it goes through the pre-filter. And the flow rate into the cleanroom is also Q a. So, the flow rate we are assuming is not inhibited by the presence of the filter, which again may not be a good assumption, as we talked about in the last lecture, especially with the final membrane filters, pressure drop can keep building, so there can be substantial losses of flow velocity with time. But in a quasi-steady state model, you can assume that, it is a reasonably steady process. So, then the out flow at this point is also going to be Q a, since its operating under steady state conditions, but part of that is now going to be recycled and part of that is going to be exhausted.

So here again, what is that mean? If Q a is the flow rate coming in here and you are now adding Q R, then this becomes some Q I, let us call it, entering the cleaned room. Q i which is equal to Q a plus Q R so, this is now actually Q i. Because it is basically a loop, in which you are taking flow and redirecting it to enter the cleanroom back in a recycle mode. So, here again this is going to change to a Q i and again you are going to keep taking some fraction of it, and so under steady state conditions, the total flow rate that enters the cleanroom is going to be, whatever you are recycling plus whatever is entering as makeup air.

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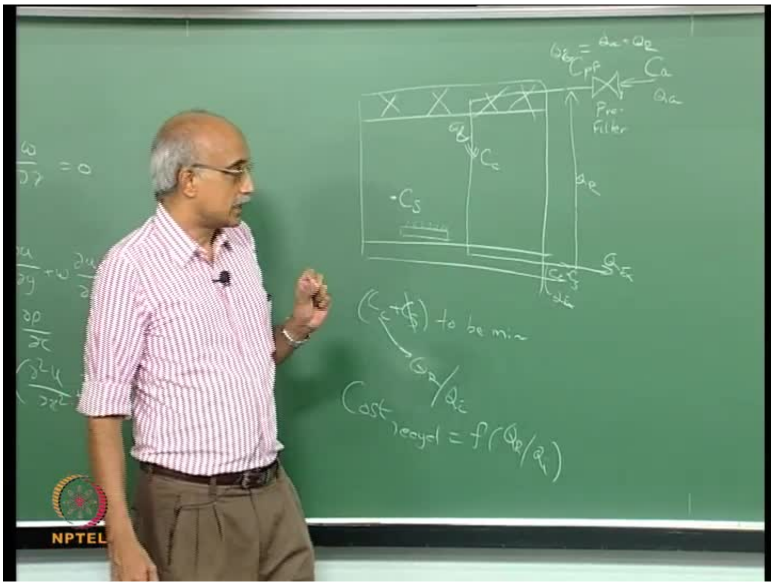

So, this is the overall flow dynamics for the cleanroom. Now, the question that we have is, if you look at this parameter C c. Let us assume that C s is constant right, it is not changing. So, what you want to actually minimize is C c plus C s. C c plus C s to be minimized or because C s is constant, we will say that C c is to be minimized.

Now, what parameter do you have control over? Let us assume that the efficiencies of the filters are fixed. So, you really cannot change that, and let us say that the outside ambient concentration is fixed, the flow rate through the filter from the ambient is fixed and let us say that. So, you do not have any control over those parameters, and let us say that is the filter efficiency of the HEPA and ULPA filters is also fixed. The parameter that you have control over is essentially, Q R over Q I, what percent of the material is being recycled back into the cleanroom. So, C c will be a function of this. And the thing is that, if C s is much greater than C a, in other words if the source inside the cleanroom is much stronger than the source outside the cleanroom, logically you would think that the less the recycle, the cleaner will be the cleanroom. Whereas, if it is the other way around, if C a is much greater than C s, you would expect that the greater the recycle, the cleaner will be the cleanroom. So, clearly these two are related. For a fixed C a value, this parameter really controls the cleanliness of the cleanroom.

But on the other hand, it is a constrained minimization problem. You cannot say, for example, if C s, if the source inside the cleanroom is much greater than the source outside, logically you would say make it 98 percent recycle and only 2 percent makeup, that is not practical, because you really cannot handle that volume of air with the pump and get it recycled, especially in a large cleanroom. So, there is a cost associated with the recycle. So, the cost of recycling also is a function of the same parameter Q R over Q i.

So, this can be formulated as a classical optimization problem, where you try to minimize C c subject to a constrained on the cost of the recycling. You set either a maximum allowed or something that is, may be based upon a relationship between quality and cost, or it may be something based on reliability and so on. But it is a constrained optimization problem. Now, if you do a simple mass balance on this, you know you can establish this relationship, using this loop you can actually calculate C c as a function of all the other parameters in this model. So, I encourage you to do that, I think it is a good exercise to setup the relationship between C c and Q R, and then try to do this as a minimization algorithm. Take d C c over d Q R equated to 0, and understand the conditions or the value of Q R which gives you a minimum in C c.

And similarly we can establish, I mean the cost is essentially going to be a linear function of the flow rate. So, the only constraint that you can place is the maximum cost. Because this is not a non-monotonic behavior, it is a monotonic behavior, the more recycling you do, the more it is going to cost your recycle. And it is fairly linear, I mean if you recycle twice the volume, you will pay twice the amount.

So, the first part I think is something that you can do separately, as a minimization exercise, and it will give you a value for Q R, which gives you a minimum in C c, and then, if you are given this number about cost of recycling, and you are given that something is the maximum that you can afford to pay, then you can compare your optimum value of the recycling rate to the maximum value that is allowed, from a cost view point and ensure that you are below that level. If you are not, then you have operate under sub optimal conditions. You have to reduce the amount of recycling, and perhaps live with the higher C c value, but with the correspondingly lower cost.

So, that is a kind of exercise that cleanroom engineers go through. No manufacturer has infinite resources that are disposal. So, they are constantly doing this juggling, to see what is achievable versus what is desirable, given the process economics and so on.

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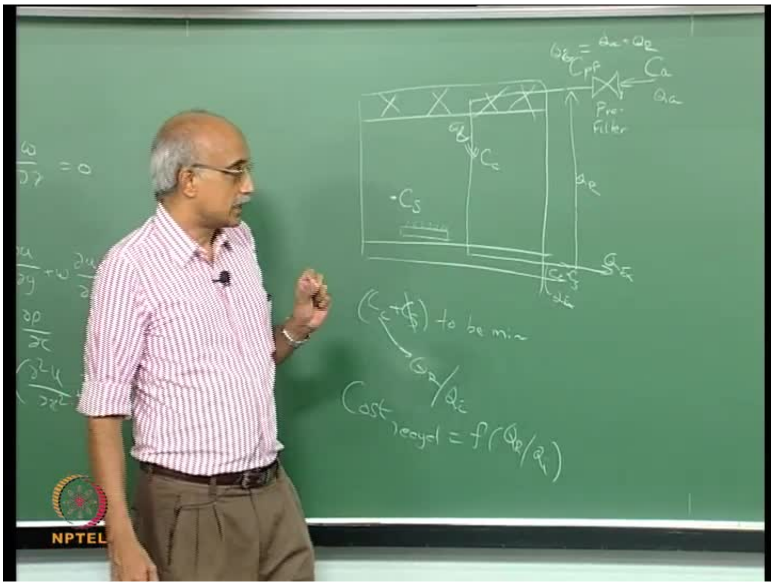

Now, this also indicates that, you know as I have said before, if cannot measure something, you cannot control it. I mean, the assumption here is, we know what these values are, but how do you quantify c s, how do you quantify C c. So, you need good equipment and instrumentation to be able to measure particles in the cleanroom air as well as on cleanroom surfaces. You might want to know, how many particles are there on a work stations inside the cleanroom, how do you evaluate them. Because until and unless you know that, you really cannot estimate these concentration values. So, methods of measuring particle concentrations become important, when you are doing this modeling of a cleanroom and trying to optimize its operation from a cost view point.

Now, the other thing also you have to keep in mind is, when you solve the Navier-Stokes equations or even the simplified quasi steady model, what you are really getting is a picture of how air flow is developing over the cleanroom. And if you solve the two phase model, you can also get a description of particle velocities inside the cleanroom, you will get a distribution of particle velocities. But from that you have to extract particle deposition rates. Now, as we have discussed in earlier lectures, the rate of deposition of particles on surfaces is the distinct parameter from the velocity with which the particles are transported inside the cleanroom. So, if you look at for example, this cleanroom, what you really care about is; suppose you have a silicon wafer sitting here, how many particles are going to deposit per unit area for some period of time. Ultimately, that is what you care about. You are not going to shift the cleanroom to the customer, what you are going to shift to the customer is the wafer that you make in the cleanroom. And if you can make a clean wafer inside a very dirty cleanroom, then you do not care, you do not care how clean the cleanroom is. But unfortunately, that is not how it works. I mean, basically if your cleanroom is clean, you get a clean wafer; if your cleanroom is dirty, you get a dirty wafer.

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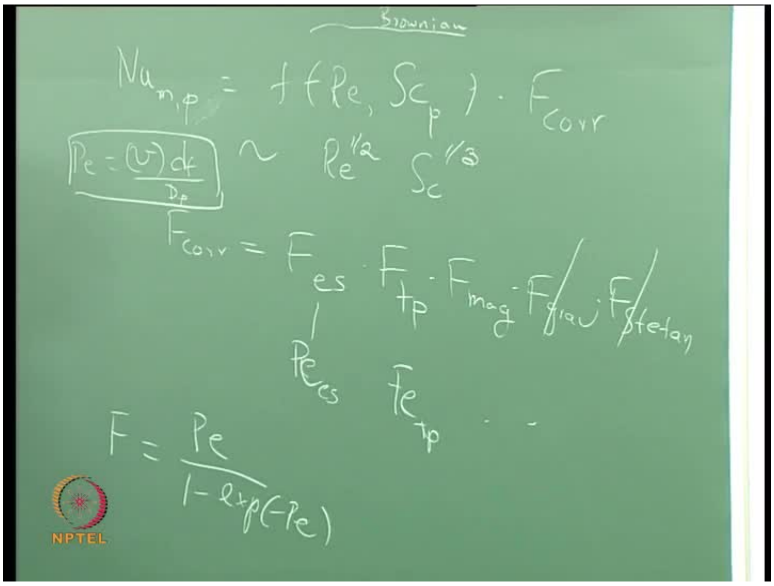

So, there is the correlation between the two. But ultimately, what you care about is keeping your product clean. So, what we need to think about is again the Nusselt number for mass transfer. So in this case, the Nusselt number for mass transfer for particles becomes the most critical dimensionless parameters that we need to track inside the cleanroom. Now, this number is a function essentially of the Reynolds number and the Schmitt number, as we have seen before. And again normally this would go approximately as, Reynolds number to the power half Schmitt number to the power one-third; where of course, the Schmitt number is the ratio of nu by d, momentum diffusivity to particle diffusivity. But this is under, what conditions? The zero conditions, assuming that there are no phoretic phenomena. But inside a cleanroom, actually the phoretic forces are very strong, because for one thing electrostatic forces are pretty high in magnitude inside a cleanroom. The reason for that is that, the cleanroom is so clean that static charges develop very easily. Low humidity conditions are especially conducive to development of charge. I do not know if you have noticed it, but the drier the atmosphere, the more that static charge develops, you can almost feel it, and cleanrooms are operated with tight controls on temperature and humidity.

Humidity is typically kept to 55 to 60 percent or less. So under such conditions, static charges develop very quickly inside a cleanroom. So, if you look at forces that deliver particles to surfaces inside a cleanroom, electrostatic forces are probability number one, in addition to the normal mechanisms of convection and diffusion and so on, which are accounted for in the Nusselt number, but you remember that we have to then multiply this with an F correction. So, this basic only involves convective and Brownian deposition of particles. In order to account for all the other phoretic phenomena, you have to apply a correction factor. So, this F correction is, will have F due to electrostatic forces, and it will also have a correction factor due to thermo phoretic forces. Because again in a cleanroom, the wafers the product that that is being worked on, will tend to be at a slightly elevated temperature compared to the facility away from the product.

Just because there are people nearby, there are tools during operations, all of that in addition to generating mass, also generates heat. So, the product that you are working on inside a cleanroom is always going to be hotter than the environment surrounding it. So, there will a temperature gradient that develops. And as soon as there is a temperature gradient, you have thermophoresis as a force to deal with. So, you have to add in a correction factor for thermophoresis.

Now, what other forces do you have to worry about? If you are handling magnetic particles, for example, if you are doing disk drive manufacturing, the disk itself has magnetic media. So, it is very lightly that many of the particles that become air bond are also magnetic in nature, in which case, you may have to have a correction factor for magnetic forces. The other type of flow that we have talked about earlier is gravitational. Unlikely, in a cleanroom it is very unlikely that you have large enough particles that gravitational settling or sedimentation becomes an issue, because these filters are very effective in removing such large particles. So, F gravitation is considered negligible inside most operational cleanrooms.

The other effect that we have talked about is Stefan flow, which happens because of a convective flow that opposes diffusion, but that again is unlikely to be important because Stefan flow is only important for non-dilute systems, where there are significant concentrations of particles in suspension. And if you do not have that, then you do not have to worry about Stefan flow also. So, the last two can be neglected. But electrostatic effects, thermophoertic effects and magnetic effects, in some cases, are important correction factors that you have develop and apply, as appropriate. Now, how do you do that? You may remember that, for each of them there is an associated Peclet number.

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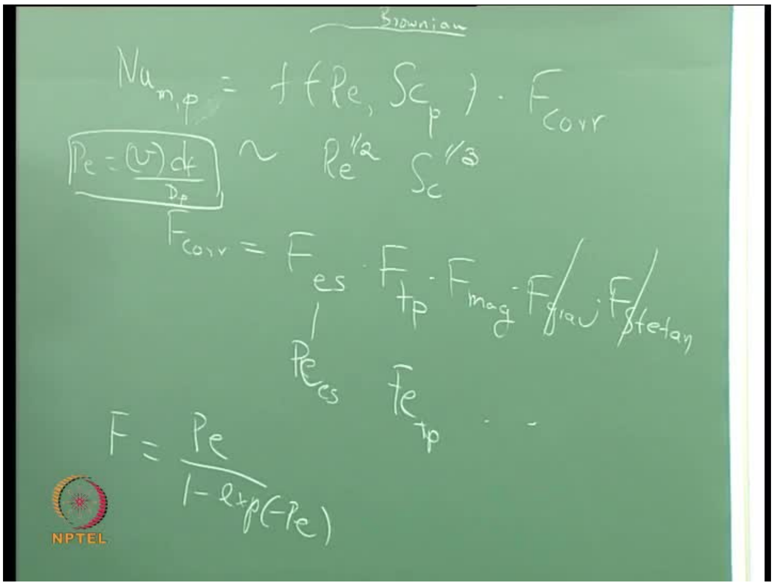

So, there is a Peclet number for electrostatic, Peclet number for thermophoresis and so on. And the correction factor itself is typically written as; Peclet number divided by 1 minus exponential of minus Peclet number; where the Peclet number is defined as a characteristic velocity that is associated with the phoretic force. So, this could be a electrostatic velocity, it could be a thermophoretic velocity or it could be a magnetophoretic velocity, and it is multiplied by a characteristic dimension. So, in this case the characteristic dimension would most likely be either the diameter of the wafer, if it a circular wafer or it could be the length of the wafer, but some characteristic length of the deposition surface divided by a diffusivity value, which measures the importance of these mechanism relative to diffusional mechanisms. So, for each of these you calculate or you measure the corresponding velocities, develop the Peclet numbers. From the Peclet numbers, you arrive at the correction factors, and then you apply that to the Nusselt number to get the actual. So, this is the prevailing Nusselt number, which is the multiple of the convective plus Brownian position of the Nusselt number times these correction factors.

So, once you know the Nusselt numbers, you can calculate the associated rate of deposition by multiplying this by the reference quantity for deposition flux.

Now, this exercise is important to do because, the thing that we need to really work on inside a cleanroom is, in addition to controlling the particulate levels in the environment, the placement, orientation and time of exposure of product are the three most important variables.

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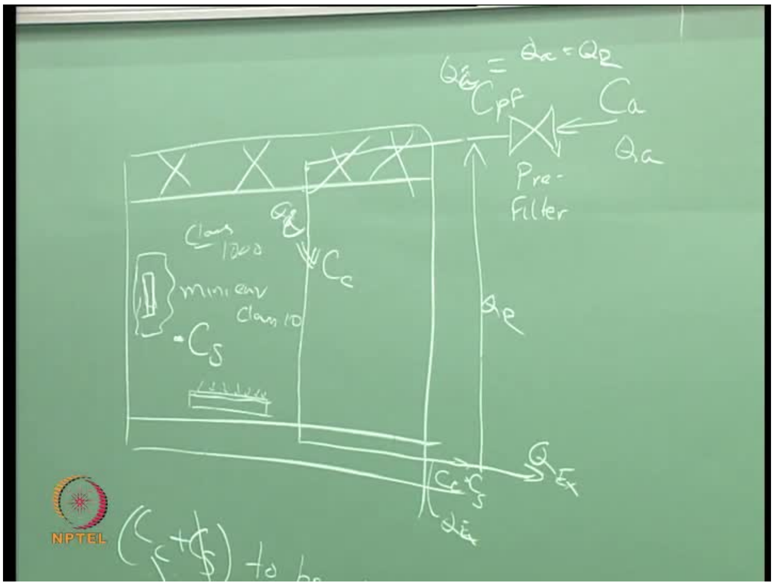

Placement, because if you place your wafer here, the rate of deposition may be very high, but may be if you place it over here, it is very low. So, you have do some mapping of air flows particle levels in the cleanroom, identify regions that are relatively clean compared to regions that are dirty, and make sure that you perform your most critical processes and expose your most critical components only in the cleanest locations.

So, location is important. Orientation is important because, if you orient the surface horizontally in this example, the rate of deposition is going to be very high, because stagnation flow can develop over the wafer. Whereas, if you located it in a configuration where it is parallel to flow, then deposition due to impaction, for example, will be distinctly reduced. And the time of exposure is critical, because rate of deposition is essentially a time dependent process; the longer you expose the surface, the more material will deposit on the surface. So, even in a very dirty cleanroom, if you have a way of providing, what is known as mini environments, these are enclosures that fit around the product that you are making, then you can actually protect the product. For example, in this cleanroom, the entire cleanroom may be across one thousand, which as you know it is pretty dirty, but around the product you can actually design a mini environment, which is a class ten. So, it is a hundred times cleaner and you make sure that you never take that product out of this mini environment. So, this could be like a cassette carrier. So, the wafers could be placed inside the cassettes, and the cassettes could be loaded inside this mini environment, and you could just move the entire mini environment from the stage to stage in the process. So that way, you do not really expose your product to a dirty environment for very long, you essentially keep it sealed in a sterile environment as long as possible, just before you are ready to do something to it, for example, you want to take the wafer and put a pattern on it, so just before you are ready to put the pattern, you remove the disk from the wafer, I mean you remove the wafer from the cassette, put the pattern on it and immediately put it back into the cassette and seal it again. So, by minimizing the time of exposure, you can also control the extent to which particles can deposit on the surface.

The other thing that you should always be on the lookout for is emission rates. When you have equipment inside a cleanroom, associated with each equipment there is a rate at which particles are getting emitted from their equipment. There is a measurement technique called particles per wafer per pass, which is a very useful technique to measure particles that are being generated from cleanroom equipment.

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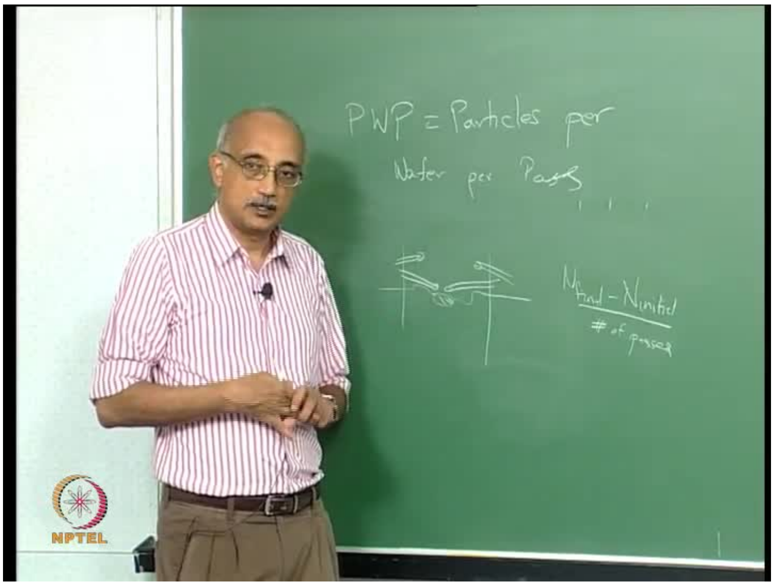

So, essentially what you do is, you take the cleaned wafer and let us say that there is some tool on which you are loading in the wafer, doing something to it, and then taking it out. So, you measure the level of particles on this wafer before it enters the equipment, then you cycle it back through this equipment ten times or hundred times, and then you measure total particles on it, after being cycled through this equipment of process, let us say hundred times. So, you take the difference between N final minus N initial and divided by number of passes through the equipment, and that is called particles per wafer per path measurement.

Now, what this is telling you is; how many particles are being added to the wafer, simply by cycling it through the process equipment that it has to go through. And it gives us a way of monitoring how clean or how the dirty this tool is. Now, what you can have is, let us say that if you have this number being measured, you can have a spec on it, you can say that if it exceeds a certain number; I am going to shut down the tool, clean it completely and then put it back online. So, it is gives you some end point control. The only down side of this type of measurement is it is somewhat after the fact, I mean what you really measuring by the time you measure this on the wafer, you would have already processed many wafers through this. So, you may have to sacrifice whatever that protection lot is, before you make the fixes. So, it is better to have a real time monitor, to look at how particles are getting emitted from the equipment. So, what we normally do is, in addition to this particle per wafer per pass methodology, in addition, we actually have particle counter tubes that are constantly measuring particle levels within this tool enclosure.

So, this is different from the particle measurement devices that we have for the clean room. Usually, the particle counters that measure clean room air are located near the filters, to measure how clean the air is when it comes into the clean room. Here, what we are talking about is locating these particle counters right where the process is been done, inside the process tool. For example, if I am putting down same patterns on this wafer inside this tool, you actually stick this particle counter as close to that operation as possible, so that you actually measure how many particles are being generated by the process of putting this pattern on the wafer.

And of course, this will also include contributions from the equipment itself, the equipment is different from the process. An equipment is just a piece of machinery. A process is what you do with our equipment. And they both have contributions to total particle levels inside the clean room, and you have to be able to measure them separately, and you have to be able to measure the clean room contamination levels separately.

So, this differentiation of sources is very important because it allows us to do a Pareto type of analysis, to identify the top contributors of particles in a cleanroom, and then take steps to minimize them. The Pareto methodology is one that essentially enables us to rank sources of particles inside a process.

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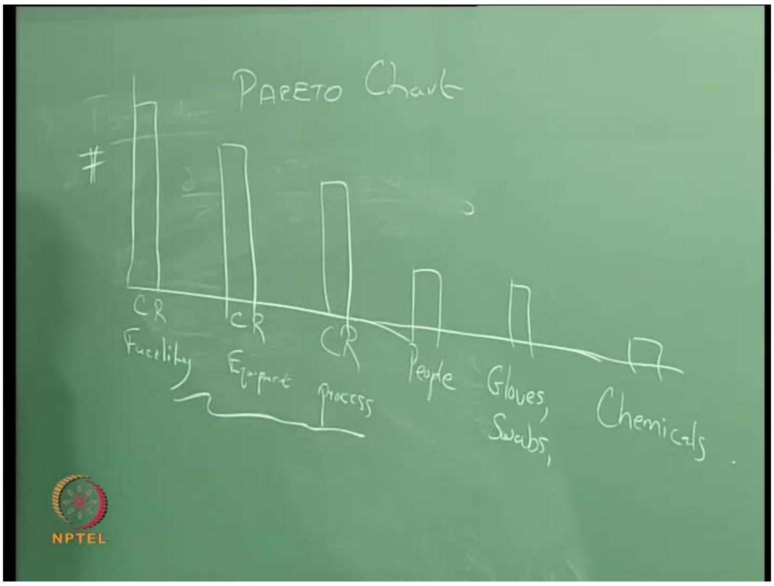

So, the way that works is; in a Pareto chart, you will take all possible sources of particles inside a clean room. So, for example, the clean room facility itself is a source, that is, the air that is coming through the filter, the filter itself, they are all sources. Clean room equipment is another source. The clean room process, what is being done inside the clean room, is a source. People are a source. The gloves, swabs, other consumables that are being used inside the clean room is a possible source. Chemicals that are used in the room are another source and so on. I mean, you can actually critically analyze and identify possible sources of particles inside a clean room, and then you actually assess the magnitude of each, so you have to have a way of measuring the number. How many particles are contributed by the facility, how many are contributed by the equipment and so on.

If you can do that quantification, then you can actually develop a bar chart. So, Pareto analysis, simply says, you draw these bar charts including all possible sources of particles in your process, and then identify the top heaters. For example, in this case we could say that, even though these are all possible sources, these three contribute 80 percent of all particles in my process. So, I am going to go after those. That is important because any organization has only limited resources, both in terms of man power as well as financial. So, you cannot cleanup everything. Ideally you would like to get a 0 particles, it is not possible. So, you want to make your investments, where they will do the most good. There is no point in spending a lot of money to cleanup your chemicals, if there are very low in your list of priority, based on the magnitude of contribution of particles, they are very low compared to some of the others.

So, the Pareto type of analysis helps you to essentially get the most bank for your buck, so to speak. It enables you to make your investments, where they will do the most good, where they will have the most dramatic effect.

So here, for example, if I find that the cleanroom facility is the biggest contributor of particles, then my first approach should be to improve the filtration, so that I can have finer filters may be, to clean up the air that is coming in. Or I may want to look at the recycle ratio, may be I am recycling too much, may be I am not recycling enough. So, I need to look at that. The other thing I would do is, look at the air flow patterns, are they really flowing in that vertical laminar flow configuration that we wanted or is something happening inside the room and I am getting mixed flow, turbulence, recirculation, stagnation. So, I would want to do some air flow modeling in this case.

On the other hand, if I find that the equipment is contributing particles, then I would want to look at; is the equipment properly designed, is it made of the right material, does it have the right surface finish, or some surfaces too rough and contributing particles by abrasion mechanisms, or is it that there was some oils that are spooling out as aerosols and getting counted as particles. If I find that the process is a major contributor, I would want to look at: do I have too many mechanical assembly processes, because when you try to, for example, screw a nut into a hole, you generate millions of particles. So, may be instead of using screws, I should be using tapes in order to assemble two components, may be much cleaner, may be you may reduce the particle generation by ten times, simply by going to an adhesive process rather than a mechanical assembly process.

Or you may find that you are just doing the process in the wrong order, may be you are not putting the components together in the right sequence, so you can just change the sequence of the assembly and improve the particle levels.

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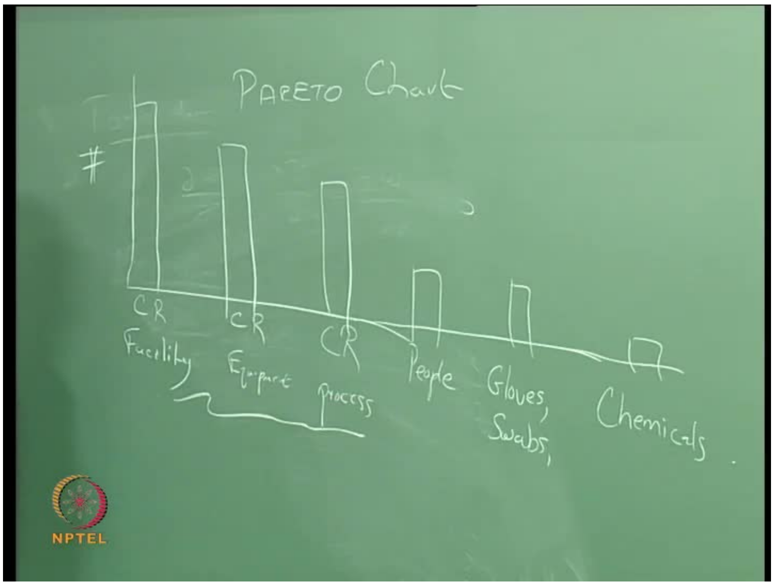

If you find that people are a major source, you know, may be they are not wearing the right garments. The primary thing that keeps people from contaminate a cleanroom is the cleanroom garment that they wear. So, maybe we have to upgrade the level of cleanroom garment that they are wearing. So, associated with each of these sources, there is a list of corrective actions, but the point is you cannot afford to implement all of these corrective actions across the board. It is too expensive too disruptive.

So, this Pareto strategy enable you to home in on specific sources that are potentially high contributors of particles and other contaminants to your process, and enables you to come up with strategies to minimize those, referentially over all the other sources.

Now, ultimately what you want to do is link this to some product performance characteristics. And when we talk about product performance, particularly in high-tech manufacturing, the two important metrics are; process yield and field reliability. These are absolutely important because process yield affects your profitability, field reliability affects customer satisfaction. And for any large volume manufacturer, those are the two most important [fl] that they live by.

If you have a high process yield and if you have high field reliability, then you are in business. If you do not, you are basically out of business. So, in the next lecture ,we will particularly focusing on these two indices; process yield and field reliability, and look at how particle characteristics, in particular, can affect these two critical parameters. Any questions on what we discussed today. See you in the next class then.