

Fundamentals of Materials Processing (Part-1)
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Lecture Number 30
Powder Characterization using Surface Area

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Techniques for Powder Characterization

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- **X-Ray Technique**
 - When particle sizes are less than few 100nm, it leads to broadening of XRD peaks
 - Scherrer formula gives the crystal or particle size D in terms of the broadening B , diffraction angle θ , and X-ray wavelength λ .
 - Gives only mean particle size with no distribution or shape information
- **Other Methods**
 - Electric pulse counter

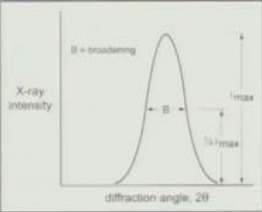


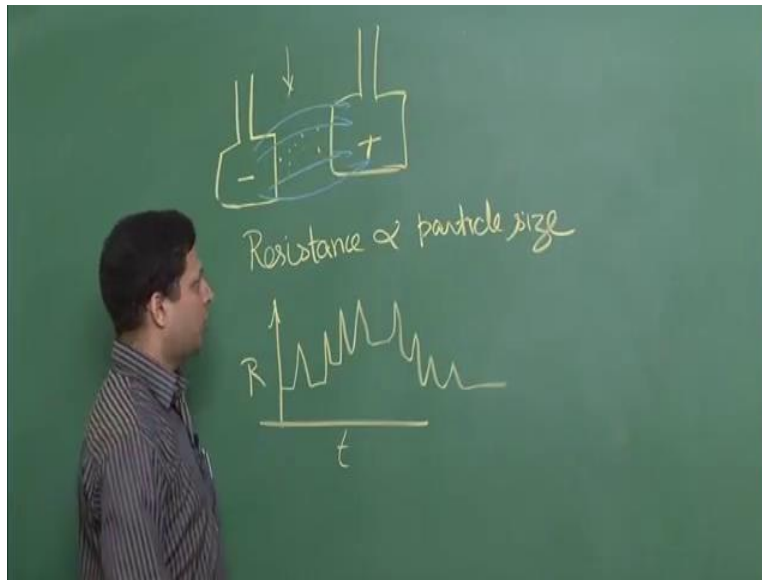
Figure 2.18. X-ray peak broadening is measured in terms of the width B at an intensity one half of the maximum.

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Okay so welcome back and we will continue our discussion on techniques for powder characterization, so we have looked at imaging technique we have looked at the screening technique and the segmentation technique and last we discussed x ray technique. So like we said that in x ray you can also use x ray diffraction because in smaller particles there incomplete destructive interference and you therefore you see broadening and there is a very common relation which is called Scherrer relation which is used to describe this broadening and relate this broadening to the size.

Now there are other than this there are also some techniques we will quickly take a look at what are what is the general modus operandi or what is the general method on which it works. So let us look at one of this which is called electric pulse counter.

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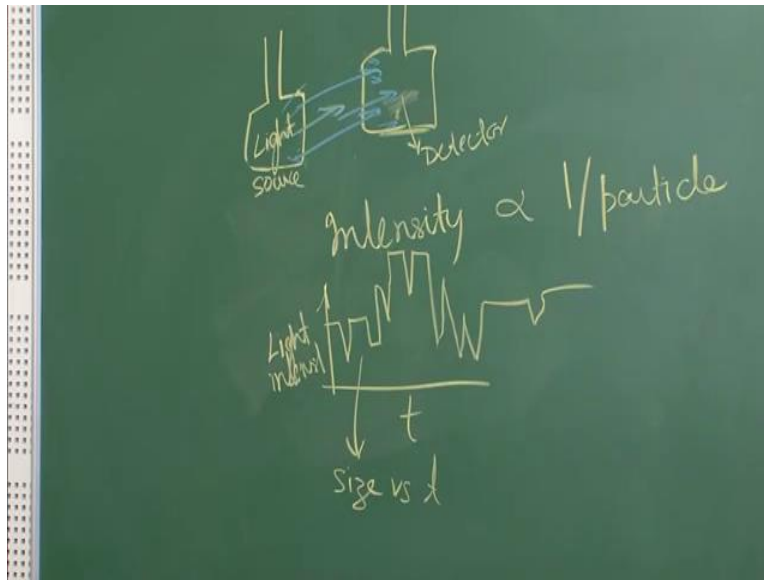


So in this what you are doing is basically you have two electrodes and these electrodes in between two electrodes, so let us say these two are the electrodes you pass the particle just like in over there you had that small cell into which the particles where flown or where fed along with the fluid.

So here also it is fed through this so let us say there are some particles over here, now there is a current flow that is established in between these two so there is some amount of current flowing these two electrodes and whenever particles come in between them the current flow will be reduced and therefore there will be resistance. So the resistance would be proportional to particles size the higher larger the particles size higher will be the resistance.

So you may get a plot something like this you measure resistance as a function of time and you may see and you can translate these resistances to the particles size and therefore with time you will have again distribution of particles in and you will be able to generate a large amount of statistics. Now similar to this electric pulse counter technique, you can also have light blocking method. So in the light blocking method what you will have is not very different but instead of two electrodes you will have a light source and a detector.

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So we can replace this with a light source and a detector again the idea is same so there is light going on from over here into this, so the intensity of light that is read by the detector intensity of the light that read by the detector is inversely proportional to the particle size the (sma) larger the particle size smaller will be the intensity. And so again you would be able to plot something like instead of intensity you can also plot adsorption but if you are plotting intensity, then you can get something like time or something like this so this is just a schematic and so depending on the magnitude and the weight you would be able to find what is the size and what is the number (disti) or what is the frequency of that particle at that particular time.

And from here so from this again you will be able to generate size versus the time distribution or the overall size distribution of the particles. So these are also some of the methods to characterize particle size. So far we have looked at the technique where we had the projected area where we had that weight fraction where we had the number fraction. Next we look at some of the techniques where surface area is actually taken into account or surface area is made use of to calculate the particle distribution or to characterize the particles.

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Surface Area

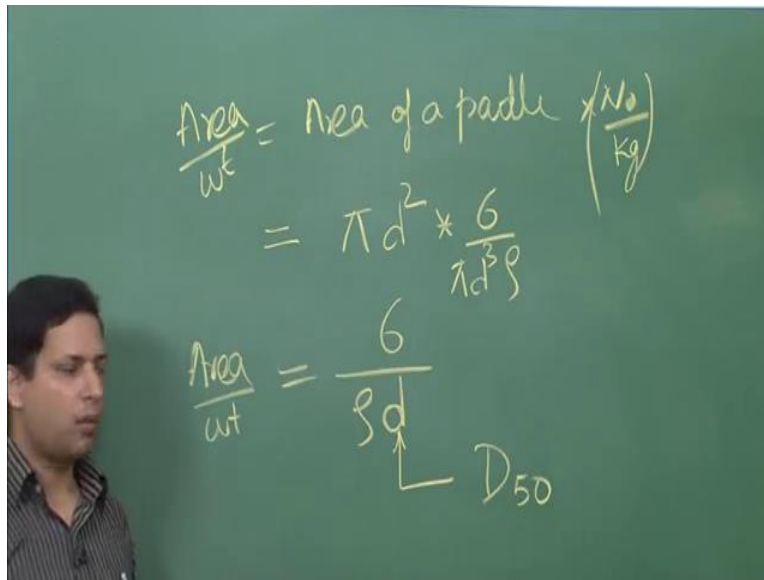
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- Average measure of the external condition of a large number of particles
- This parameter correlates with chemical reactivity, packing, adsorption, contamination, and even compaction and sintering
- For wide distribution, D_{50} is utilized for calculation of specific surface area
- Analysis techniques: Gas adsorption and gas permeability

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So the surface area is actually the average major of the external condition of a large number of particles so depending on the powders size you will have different amount of surface area that it is exposed to and it will accordingly react or interact with some the environment more or less depending on how much is the surface area available. This parameter the surface area correlates with chemical reactivity packing adsorption contamination and even compaction and sintering. So we can not only relate it with the some of the other parameters we can also related it with packing adsorption contamination compaction and sintering behavior of the material. And as you will see that when we are talking about D or equivalent D what we will again be using is nothing but D50 which is the 50 percent or the average diameter that we obtained.

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The image shows a man in a striped shirt standing to the left of a green chalkboard. The chalkboard contains the following handwritten equations:

$$\frac{\text{Area}}{\text{wt}} = \text{Area of a particle} \left(\frac{\text{m}^2}{\text{kg}} \right)$$
$$= \pi d^2 * \frac{6}{\pi d^3 \rho}$$
$$\frac{\text{Area}}{\text{wt}} = \frac{6}{\rho d}$$

An arrow points from the 'd' in the denominator of the second equation to the label 'D50' written below it.

So just to get a feel of the number again let us you remember we talked about area per unit weight which is nothing but area of one particle times number per unit kg or number per unit weight. So put it in perspective in terms of or to put it in terms of the symbols, so this is pi d square into six by pi d cube rho or this is equal to six by rho d. So whenever we are calculating area per unit weight it will have a relation like this but we need some diameter over here or we will get a diameter and the diameter that particular diameter will be actually nothing but D50. So whenever we are getting area per unit weight we will be able to calculate d diameter from there and that diameter is nothing but D50 or the median diameter.

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Surface Area

15

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- This parameter correlates with chemical reactivity, packing, adsorption, contamination, and even compaction and sintering
- For wide distribution, D_{50} is utilized for calculation of specific surface area
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The two techniques which we can utilize to measure surface area are gas adsorption and gas permeability technique. So we will look at in the next few slides how gas adsorption and gas permeability technique can describe the surface area and hence characterize the particle the particle distribution.

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Gas Adsorption Method

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- Gas adsorbed is proportional to the surface area
- Clean powder is exposed to varying partial pressures of adsorbing vapor
- BET equation relates the amount of gas adsorbed on the powder surface with the partial pressure
- The BET equation is generally valid for powders in the pressure range P/P_o from 0.05 to 0.30
- Specific surface area can be related to the above parameters

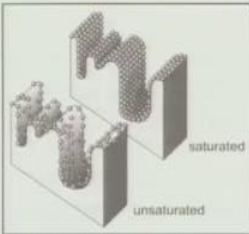


Figure 2.31. Illustration of molecular adsorption on a surface and the use of a monolayer coating at saturation to assess the surface area.

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Now let us say we have different particles we will have some uneven surfaces and on those surfaces or those surfaces will actually be interacting like we said with the environment. Now, if we expose it expose a very cleaned powder to environment where there are adsorbable gases

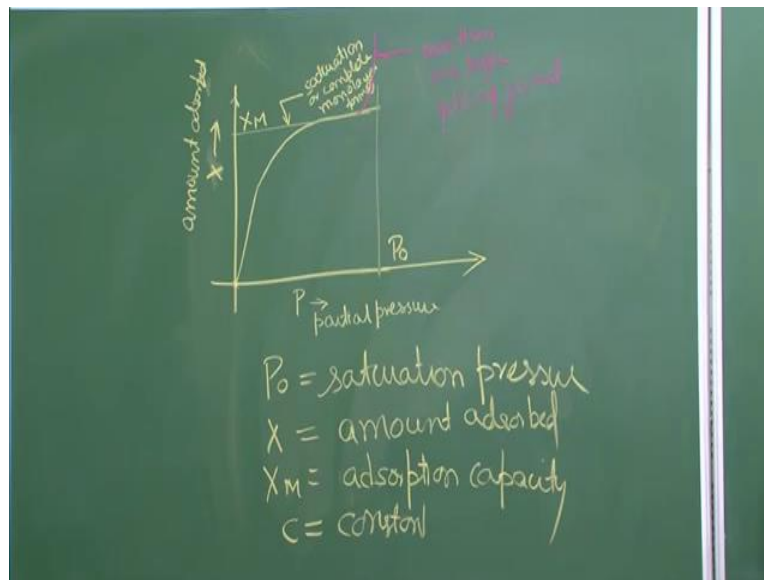
some gases which can be adsorbed onto the surface. Then this adsorbable gases will get adsorbed or stick onto the surface. So this is what is shown here so this is one of the surface at is just one cross section not a one particle but one cross section of that particle and the gases which can be adsorbed are sticking over here.

So, here still only a small number of gases have been adsorbed, Now if you keep increasing the pressure of these adsorbable molecules then there will come a point of time where the complete surface is covered with these adsorbable gases. And you will get a monolayer of this adsorbable gases onto this particle onto this so this is again one particular section of the particle and now you can say see that in the saturated state the complete surface has been covered with this adsorbable gas.

So we want to reach this state by increasing the pressure of the adsorbable gas. So we start from here we keep increasing the partial pressure of these adsorbable gases and as the partial pressure keeps increasing the amount of these gases that are sticking increases and finally we reach over here. And there is a relation which is called the BET equation which is very well known when you are in the business of characterizing in powder it relates the amount of gas absorbed on the powder surface with the partial pressure.

And then you can correlate it correlate the amount to the surface area available and total surface area that is present in the powder size and from there you will be able to get a equivalent diameter. However this BET equation is generally valid for powders in the pressure range from P/P_0 not of value changing from 0 point 05 to 0 point 3. So this is the partial pressure range in which this particular BET equation is valid and the from here like we said this can be related to your total surface area of the particles.

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So let me schematically draw what is happening over here, so let us say we increase the partial pressure so on the x axis we have partial pressure of the gas that has to be adsorbed. And on the y axis is the amount that has been adsorbed, so we will represent that by x , so what will happen at the when the partial pressure of this amount is zero so the amount of x will also be zero. So it will start from here and you keep increasing it it will also increase but then a point will come where it will reach saturation why is this reaching saturation It is reaching saturation because here the complete surface has been adsorbed or a one monolayer has been formed.

So this is the point of saturation or where monolayer completes now monolayer has been formed so this is a saturation or complete monolayer formed and this particular pressure at which it reaches this is described by P not. However it is by we have make some simplification over here and in reality what you will see is that if you keep increasing the pressure then even before complete saturation has been reached the amount of gas adsorbed increases. What does that mean? It means now that this starts to form more than one layer are getting formed.

So this is how the real situation would look like when you keep increasing the partial pressure it will asymptotically reach a saturation value which is denoted by x_M but even before it completely reaches that exponential or that asymptotically that x_M value at that particular pressure P not it start to increase again exponentially and that is because now more than one

layer start to form at some other places So the there is no more single layer at every place there are some places two layers three layers and four layers.

However what is important is what we need is this x_m value the amount which will be adsorbed when a monolayer is formed on all the surfaces and based on the experiment you can very easily get value for x_m So we will see what exactly needs to be done and to complete this let me also write P have already described it is partial pressure P not is the saturation pressure x is the amount adsorbed x_m we have already explained it is the adsorption capacity or more one monolayer is formed and we will introduce another term which is just a constant to get what is called as a BET relation.

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BET (Brunauer, Emmett & Teller)

$$\frac{P}{x(P_0 - P)} = \frac{1}{x_m C} \left[1 + \frac{P}{B} (C-1) \right]$$

$$y \left\{ \frac{P}{x(P_0 - P)} \right\} = B + A \left(\frac{P}{P_0} \right) \leftarrow x$$

So we will write down the BET relation that is used to obtain the value of x_m . Now when we are talking about BET it is important that I also mention what is this BET stand for it is named after three scientists who came up or who derived this relation Brunauer Emmett Teller so they have this BET relation which says that P over you see the terms are already defined earlier. So this is a BET relation but over here we will not be able to distinguish each and every quantity and experiment in experiment what you would do is you will plot P over P not verse x ($P-P$ not).

So this will become your y also let me put it like this this is your x P not P by X P by x times (P not - P) this is like y or this is the response that you are getting and these are constants so we can put it something like this this and it can be plotted against this value which will become your x .

So you plot or you see this response y in terms of this input P over P not so you keep changing partial pressure and therefore P by P not changes and knowing upon knowing the x value you can derive or you can get form of equation like this or form of quantity like this which will be your response that you are measuring so you measure this response against this input and you will get a relation which is linear in form.

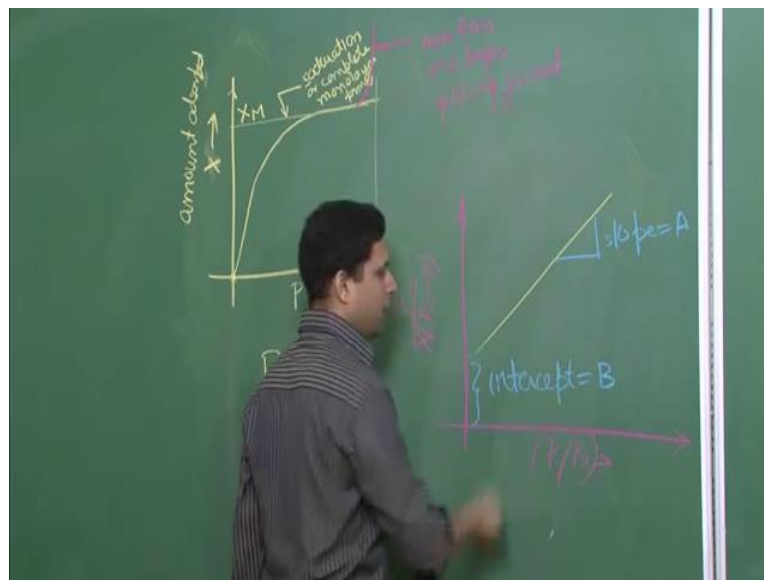
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BET (Brauauer, Emmelt & Teller)

$$\frac{P}{X(P_0 - P)} = \frac{1}{X_M C} \left[1 + \frac{P}{B} (C-1) \right]$$

$$y \left\{ \frac{P}{X(P_0 - P)} = B + A \left(\frac{P}{P_0} \right) \leftarrow x \right.$$

$$X_M = \frac{1}{A+B}$$

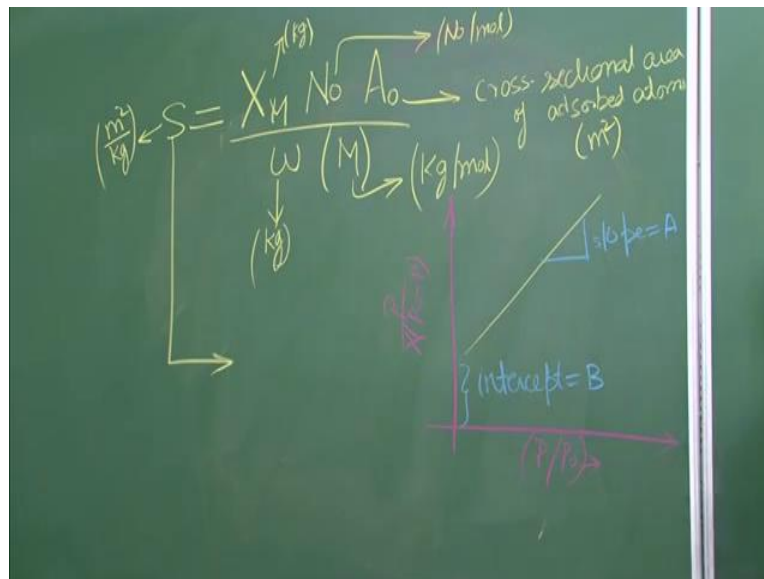


So it will if you were to draw this it is how this is how it will look like on the x axis which is our input the parameter that we are changing it is this and on the y axis we have this is the measured value and you can plot it and you would see that you will get a straight line like this because it is

of the form y equal to mx plus c so this becomes your slope and this intercept becomes your B . So from this once you have been able to do conduct this experiment you would get a relation like this and from there you will get slope and you will get intercept and once you have A and B values then calculating the x_m becomes very simple with can you can easily show that x_m which is the value that we are interested in is equal to one over A plus B .

We were interested in x_m because x_m is what we will be able to relate to the total surface area. So once you do this experiment you get the slope and the intercept and from there you get the x_m value and next we will use this x_m value to get what is the surface area which is given like this.

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Now here the surface area that we are calculating is being calculated per unit weight because we keep increasing it it is linearly proportional to the weights so we can calculate this in terms of per unit weight and the usual unit for this would be meter square per kg x_m we already know and the unit for this would be kg the amount that has been absorbed weight is the total weight of the sample for which you are doing the experiment.

So again this will we in the weights in the units of weight in the units of kg and this is the molecular mass which will be in the units of kg per mole and N not is the Avogadro number which would be number per unit mole and A not here represents the cross sectional area of the adsorbed atoms. So this is cross sectional area of adsorbed atoms and for the uniformity in units you will have to express it in meter square. So you see this number will be known this will be

known this will be known and this will be known and this is the value that you will obtain from the BET equation and once you have that value from over here you will get what is the surface area per unit kg.

And then once you have the surface area per unit kg we can calculate D50 or the median diameter like we showed earlier. You can just compare surface area per unit kg from one particular condition to another condition to understand what is the particle size and you can even put together particle sizes of different different distribution and get surface area per unit kg for them and then get a plot of surface area per as a function of size.

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Gas Permeability Method

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- Permeability of a gas passing through a porous structure also depends on the surface area of a **compact**. **How?**
- Darcy's equation relates flow rate Q with drop in pressure ΔP
- Kozeny and Carman equation relates surface area of the compact to the permeability through the fractional porosity ϵ
- Technique is suitable for particles in the 0.5 to 50 μm range
- The measurements are not accurate as it does not take into account the closed pores that contribute to surface area, but only those that participate in gas flow
- Hence, this method normally underestimates surface area w.r.t. BET

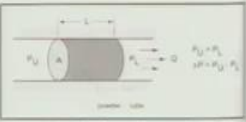


Figure 2.34: The determination of powder surface area by gas permeability is possible by measuring the flow rate of a gas through a packed powder bed at a known pressure differential.

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So this is the method that is used for another method that is used to get surface area and then which is translated to particle size characterization. Now this is not the only method that uses the surface that measures the surface area and which is then translated to the to the particle size characterization there is steel another method which is called a gas permeability method. The permeability of a gas passing through a porous structure depends on the surface area of a compact.

Now you can imagine one of the places permeability is very commonly used is in the molds you are looking at the sand molds you want to know how much permeability it has because you want to allow the gases to pass through it. Now that if they were concrete block then you would not see any gas passing through it and so permeability will negligible will be zero. However when

you have a porous structure for example the grain sand mold or in this particular case you have taken the powder and compacted it then through this porous structure gas will be able to pass through.

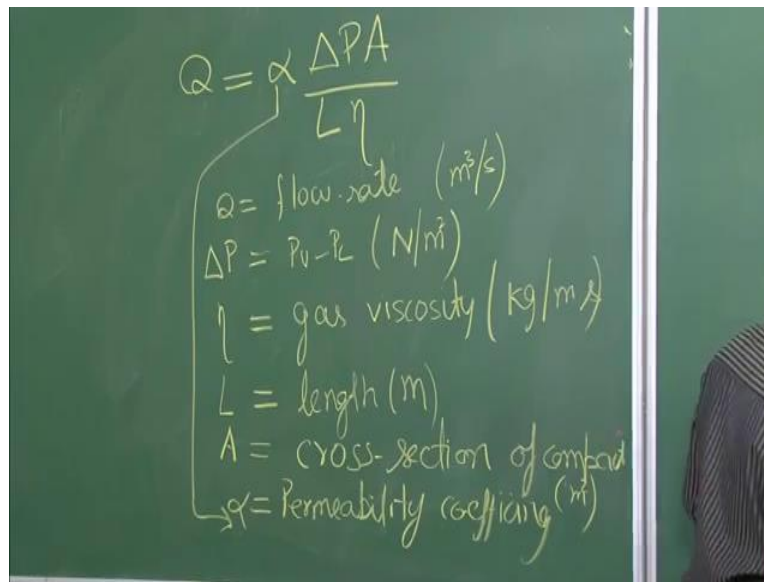
And since it is porous structure. The amount of gas that is able to pass through represents the surface area available Now there is a relation which is called Darcy's relation which related flow rate Q or in effect the permeability with drop in pressure ΔP so if you take a compact as shown in the figure here this is the powder compact okay so there will be inside if you go inside there will be lot of porosity and there will be surface area related to that porosity.

Now if you allow a gas to pass through it there will be a pressure difference that will develop P_l and over here P_u so there total pressure difference is $P_u - P_l$ and because of that pressure difference and that pressure difference is developing, because the gas is flowing through it and the gas flow rate is given by this quantity Q .

And then there is another equation which is called Kozeny and Carman equation which relates surface area of the compact to the permeability through the fractional porosity. So we will look at these equations in just a moment but it from the first relation you get a proportionality constant that proportionality constant is then used in the second equation to find the surface area in terms of fractional porosity ϵ and we will also look at what is this fractional porosity ϵ .

So let us start with so basically at this point you should be clear how gas permeability is related to the surface area because if it is a very very porous structure more gas will pass through it and if more gas is passing through it means there is largest surface area or large porosity. So the amount of porosity is related to surface area and amount of porosity is related to amount of gas passing through it. So that is the basic principle which is used in utilizing permeability to measure by or to characterize size.

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$$Q = \alpha \frac{\Delta P A}{L \eta}$$

$Q = \text{flow rate (m}^3/\text{s)}$
 $\Delta P = P_u - P_l \text{ (N/m}^2\text{)}$
 $\eta = \text{gas viscosity (kg/m.s)}$
 $L = \text{length (m)}$
 $A = \text{cross-section of compact}$
 $\alpha = \text{permeability coefficient (m}^2\text{)}$

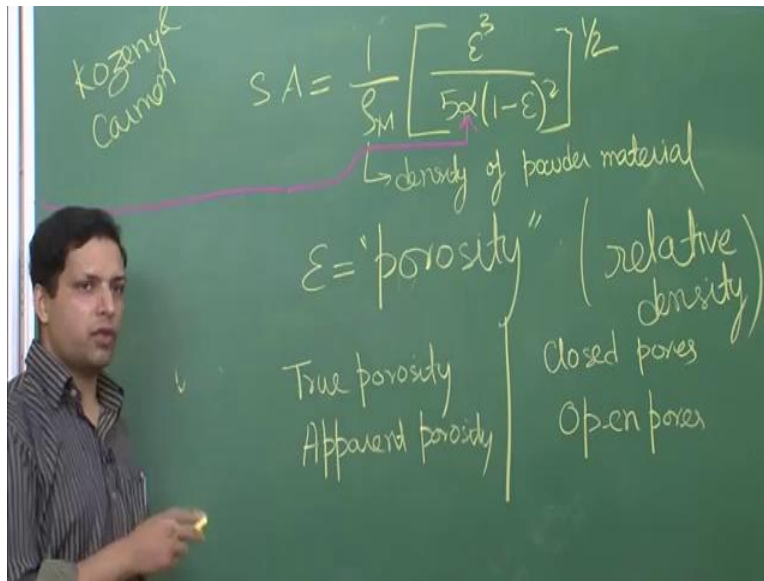
So now let us get back to the board and look in terms of equation what they mean. So the first one is the Darcy relation which relates Q or the amount of gas passing through because of permeability through the compact so there is this proportionality constant α there is this ΔP there is A there is L and there is η . So what are these quantities? Let us define Q is the flow rate we have already said that flow rate because of the permeability and the units will be in meter cube per second.

ΔP is equal $P_u - P_l$ and the unit of that is the pressure and the units will be Newton per meter square η is the gas viscosity so gas viscosity also has a role to play over here and the units will be kg per meter second L is the total length of the compact through which we are measuring so it will have the units of meter A is similar to the cross sectional area that we talked earlier no it is a sorry in this particular case it is the cross sectional area of the compact so the units will be meter square and α is the permeability coefficient.

So this relation is relating or this equation is relating flow rate with the ΔP and that ΔP is generated because there is porosity. So the α becomes the permeability coefficient and this permeability coefficient we will utilize so in the next equation, so what is happening here is you will do the experiment to measure flow rate once and you will measure the ΔP you know the A you know the L and you know the η .

So now from here you will be able to calculate alpha and once you have that alpha we will use it in the next relation that we will soon be talking about. So we use it in the next relation which is the Kozeny and Carman relation which relates this alpha to the surface area through this parameter porosity.

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So this is our Kozeny and Carman relation which says that surface area is equal to 1 over rho m epsilon cube by five alpha one minus epsilon square and everything under root. So rho m you can realize it is density of metal law material basically the powder particle that we are looking at this is the true density so the true density of a bulk density and it is this alpha that we talked about earlier so you can see this is obtained over here and it is being utilized over here. So the alpha you get from the previous equation use over here and relate it to get surface area. Now this is not all here we have some term called as epsilon and now it is important to understand what is this term epsilon. This term epsilon is used for porosity so we need a way to define porosity and this porosity is related to what it is basically related to relative density.

Now this porosity that we have over here we need to have a formal way to say what is exactly porosity and therefore we will need some other parameters like true porosity will look at it in more detail in the next lecture, but for now let me just define the terms that we will be dealing with true porosity and apparent porosity and when we are talking about pores there may be closed pores and open pores. And you will see that since there are at least two these two different

kind of pores the surface area that you calculate using this method will be different can be different from the surface area that we calculated in the previous method which was the adsorption technique.

And therefore we will again will have to understand it in much more we should understand it in greater detail so that we can differentiate why the two methods are different and what we will see is that the surface area calculated by this method which is the gas permeability method underestimates the surface area than the the surface area calculated by BET method So we will come back to this and we will define this term porosity in the next lecture when we meet in the next class. So thank you and see you in the next class.

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So here also it is fed through this, so let us say there are some particles over here, now there is a current flow that is established in between these two, so there is some amount of current flowing these two electrodes and whenever particles come in between them, the current flow will be reduced and therefore there will be resistance. So the resistance would be proportional to particles size, the higher larger the particles size, higher will be the resistance.

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So we can replace this with a light source and a detector, again the idea is same so there is light going on from over here into this, so the intensity of light that is read by the detector, intensity of the light that read by the detector is inversely proportional to the particle size, the (sma) larger the particle size smaller will be the intensity. And so again you would be able to plot something like, instead of intensity you can also plot absorption but if you are plotting intensity, then you can get something like time, or something like this, so this is just a schematic and so depending on the magnitude and the weight, you would be able to find what is the size and what is the number (disti) or what is the frequency of that particle at that particular time.

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So just to get a feel of the number again let us, you remember we talked about area per unit weight which is nothing but area of one particle times number per unit kg or number per unit weight. So put it in perspective in terms of or to put it in terms of the symbols, so this is πd^2 into six by πd^3 row or this is equal to six by row d. So whenever we are calculating area per unit weight, it will have a relation like this but we need some diameter over here or we will get a diameter and the diameter that particular diameter will be actually nothing but D50. So whenever we are getting area per unit weight, we will be able to calculate d diameter from there and that diameter is nothing but D50 or the median diameter.

The two techniques which we can utilize to measure surface area are gas adsorption and gas permeability technique. So we will look at in the next few slides how gas adsorption and gas permeability technique can describe the surface area and hence characterize the particle the particle distribution.

Now let us say we have different particles we will have some uneven surfaces and on those surfaces or those surfaces will actually be interacting like we said with the environment. Now if we expose it, expose a very cleaned powder to environment where there are adsorbable gases, some gases which can be adsorbed onto the surface. Then this adsorbable gases will get adsorbed

or stick onto the surface. So this is what is shown here, so this is one of the surface at is just one cross section not a one particle, but one cross section of that particle and the gases which can be adsorbed are sticking over here.

So here, still only a small number of gases have been adsorbed. Now if you keep increasing the pressure of these adsorbable molecules, then there will come a point of time where the complete surface is covered with these adsorbable gases. And you will get a monolayer of this adsorbable gases onto this particle, onto this so this is again one particular section of the particle and now you can say see that in the saturated state, the complete surface has been covered with this adsorbable gas.

So we want to reach this state by increasing the pressure of the adsorbable gas. So we start from here we keep increasing the partial pressure of these adsorbable gases and as the partial pressure keeps increasing the amount of these gases that are sticking increases and finally we reach over here. And there is a relation which is called the BET equation which is very well known when you are in the business of characterizing in powder, it relates the amount of gas absorbed on the powder surface with the partial pressure.

And then you can correlate it, correlate the amount to the surface area available and total surface area that is present in the powder size and from there you will be able to get a equivalent diameter. However this BET equation is generally valid for powders in the pressure range from P/P_0 of value changing from 0.05 to 0.3. So this is the partial pressure range in which this particular BET equation is valid and th from here like we said, this can be related to your total surface area of the particles.

So let me schematically draw what is happening over here, so let us say we increase the partial pressure, so on the x axis we have partial pressure of the gas that has to be adsorbed. And on the y axis is the amount that has been adsorbed, so we will represent that by x, so what will happen at the when the partial pressure of this amount is zero, so the amount of x will also be zero so it will start from here and you keep increasing it, it will also increase but then a point will come where it will reach saturation, why is this reaching saturation? It is reaching saturation because here the complete surface has been adsorbed or a one monolayer has been formed.

So this is the point of saturation or where monolayer completes now monolayer has been formed, so this is a saturation or complete monolayer formed and this particular pressure at which it reaches this is described by P_{not} . However, it is by we have make some simplification over here and in reality what you will see is that if you keep increasing the pressure, then even before complete saturation has been reached, the amount of gas adsorbed increases. What does that mean? It means now that this starts to form more than one layer are getting formed.

So this is how the real situation would look like when you keep increasing the partial pressure, it will asymptotically reach a saturation value which is denoted by x_m , but even before it completely reaches that exponential or that asymptotically that x_m value at that particular pressure P_{not} it start to increase again exponentially and that is because now more than one layer start to form at some other places. So the, there is no more single layer at every place, there are some places two layers, three layers and four layers.

However, what is important is what we need is this x_m value, the amount which will be adsorbed when a monolayer is formed on all the surfaces and based on the experiment you can very easily get value for x_m . So we will see what exactly needs to be done, and to complete this let me also write P have already described it is partial pressure, P_{not} is the saturation pressure, x is the amount adsorbed, x_m we have already explained it is the adsorption capacity or more one monolayer is formed and we will introduce another term which is just a constant to get what is called as a BET relation.

So we will write down the BET relation that is used to obtain the value of x_m . Now when we are talking about BET it is important that I also mention what is this BET stand for, it is named after three scientists who came up or who derived this relation, Brunauer, Emmett, Teller, so they have this BET relation which says that P over you see the terms are already defined earlier, so this is a BET relation but over here we will not be able to distinguish each and every quantity and experiment, in experiment what you would do is you will plot P over P_{not} verse x (P_{not}).

So this will become your y , also let me put it like this, this is your x P_{not} , P by X P by x times ($P_{not} - P$) this is like y or this is the response that you are getting and these are constants so we can put it something like this, this and it can be plotted against this value which will become

your x . So you plot or you see this response y in terms of this input P over P not, so you keep changing partial pressure and therefore P by P not changes and knowing upon, knowing the x value you can derive or you can get form of equation like this or form of quantity like this which will be your response that you are measuring, so you measure this response against this input and you will get a relation which is linear in form.

So it will if you were to draw this, it is how, this is how it will look like, on the x axis which is our input the parameter that we are changing it is this and on the y axis we have this is the measured value and you can plot it and you would see that you will get a straight line like this, because it is of the form y equal to mx plus c , so this becomes your slope and this intercept becomes your B . So from this once you have been able to do conduct this experiment you would get a relation like this and from there you will get slope and you will get intercept and once you have A and B values, then calculating the x_m becomes very simple with can you can easily show that x_m which is the value that we are interested in is equal to one over A plus B .

We were interested in x_m , because x_m is what we will be able to relate to the total surface area. So once you do this experiment, you get the slope and the intercept and from there you get the x_m value and next we will use this x_m value to get what is the surface area which is given like this.

Now here the surface area that we are calculating is being calculated per unit weight because we keep increasing it, it is linearly proportional to the weights, so we can calculate this in terms of per unit weight and the usual unit for this would be meter square per kg, x_m we already know and the unit for this would be kg the amount that has been absorbed, weight is the total weight of the sample for which you are doing the experiment.

So again this will we in the weights, in the units of weight in the units of kg and this is the molecular mass which will be in the units of kg per mole and N not is the Avogadro number which would be number per unit mole and A not here represents the cross sectional area of the adsorbed atoms. So this is cross sectional area of adsorbed atoms and for the uniformity in units

you will have to express it in meter square. So you see this number will be known, this will be known, this will be known and this will be known and this is the value that you will obtain from the BET equation and once you have that value from over here, you will get what is the surface area per unit kg.

And then, once you have the surface area per unit kg, we can calculate D50 or the median diameter like we showed earlier. You can just compare surface area per unit kg from one particular condition to another condition to understand what is the particle size, and you can even put together particle sizes of different different distribution and get surface area per unit kg for them and then get a plot of surface area per as a function of size.

So this is the method that is used for another method that is used to get surface area and then which is translated to particle size characterization. Now this is not the only method that uses the surface that measures the surface area and which is then translated to the, to the particle size characterization, there is still another method which is called a gas permeability method. The permeability of a gas passing through a porous structure depends on the surface area of a compact.

Now you can imagine one of the places permeability is very commonly used is in the molds, you are looking at the sand molds you want to know how much permeability it has, because you want to allow the gases to pass through it. Now that, if they were concrete block, then you would not see any gas passing through it and so permeability will negligible will be zero. However, when you have a porous structure, for example the gran sand mold or in this particular case you have taken the powder and compacted it, then through this porous structure gas will be able to pass through.

And since it is porous structure. The amount of gas that is able to pass through represents the surface area available. Now there is a relation which is called Darcy's relation which related flow rate Q or in effect the permeability with drop in pressure ΔP . so if you take a compact as shown in the figure here, this is the powder compact okay, so there will be inside if you go inside there will be lot of porosity and there will be surface area related to that porosity.

Now if you allow a gas to pass through it, there will be a pressure difference that will develop P_l and over here P_u , so there total pressure difference is $P_u - P_l$ and because of that pressure difference and that pressure difference is developing because the gas is flowing through it and the gas flow rate is given by this quantity Q .

And then there is another equation which is called Kozeny and Carman equation which relates surface area of the compact to the permeability through the fractional porosity. So we will look at these equations in just a moment but it from the first relation you get a proportionality constant that proportionality constant is then used in the second equation to find the surface area in terms of fractional porosity ϵ and we will also look at what is this fractional porosity ϵ .

So let us start with so basically at this point you should be clear how gas permeability is related to the surface area because if it is a very very porous structure, more gas will pass through it and if more gas is passing through it means there is largest surface area or large porosity. So the amount of porosity is related to surface area and amount of porosity is related to amount of gas passing through it. So that is the basic principle which is used in utilizing permeability to measure by or to characterize size.

So now let us get back to the board and look in terms of equation what they mean. So the first one is the Darcy relation which relates Q or the amount of gas passing three through because of permeability through the compact, so there is this proportionality constant α , there is this ΔP , there is A , there is L and there is η . So what are these quantities? Let us define, Q is the flow rate, we have already said that flow rate because of the permeability and the units will be in meter cube per second.

ΔP is equal $P_u - P_l$ and the unit or that is the pressure and the units will be Newton per meter square. η is the gas viscosity, so gas viscosity also has a role to play over here and the units will be kg per meter second. L is the total length of the compact through which we are measuring, so it will have the units of meter. A is similar to the cross sectional area that we talked earlier, no it is a , sorry in this particular case, it is the cross sectional area of the compact, so the units will be meter square and α is the permeability coefficient.

So this relation is relating or this equation is relating flow rate with the delta P and that delta P is generated because there is porosity. So the alpha becomes the permeability coefficient and this permeability coefficient we will utilize, so in the next equation, so what is happening here is you will do the experiment to measure flow rate once and you will measure the delta P, you know the A, you know the L, and you know the eta.

So now from here, you will be able to calculate alpha and once you have that alpha we will use it in the next relation that we will soon be talking about. So we use it in the next relation which is the Kozeny and Carman relation which relates this alpha to the surface area through this parameter porosity.

So this is our Kozeny and Carman relation which says that surface area is equal to 1 over $\rho_m \epsilon^3$ by five alpha one minus epsilon square and everything under root. So ρ_m , you can realize it is density of metal law material, basically the powder particle that we are looking at this is the true density, so the true density of a bulk density and it is this alpha that we talked about earlier, so you can see this is obtained over here and it is being utilized over here. So the alpha you get from the previous equation use over here and relate it to get surface area. Now this is not all, here we have some term called as epsilon and now it is important to understand what is this term epsilon. This term epsilon is used for porosity, so we need a way to define porosity and this porosity is related to what, it is basically related to relative density.

Now this porosity that we have over here, we need to have a formal way to say what is exactly porosity and therefore we will need some other parameters like true porosity will look at it in more detail in the next lecture, but for now let me just define the terms that we will be dealing with, true porosity and apparent porosity and when we are talking about pores there may be closed pores and open pores. And you will see that since there are at least two these two different kind of pores, the surface area that you calculate using this method will be different, can be different from the surface area that we calculated in the previous method which was the adsorption technique.

And therefore we will again will have to understand it in much more we should understand it in greater detail so that we can differentiate why the two methods are different and what we will see

is that the surface area calculated by this method which is the gas permeability method underestimates the surface area than the the surface area calculated by BET method. So we will come back to this and we will define this term porosity in the next lecture, when we meet in the next class. So thank you and see you in the next class.