INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
NPTEL
NPTEL ONLINE CERTIFICATION COURSE
Mechanical Operations

Lecture-04
Characterization of collection of particles-1

With
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I welcome you all in the fourth lecture of week 1 of mechanical operations course.

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Which is on characterization of collection of particle part. In this particular lecture I will discuss about the collection of particles because for any product collection of particles or mixture of particles matters instead of a single particle.

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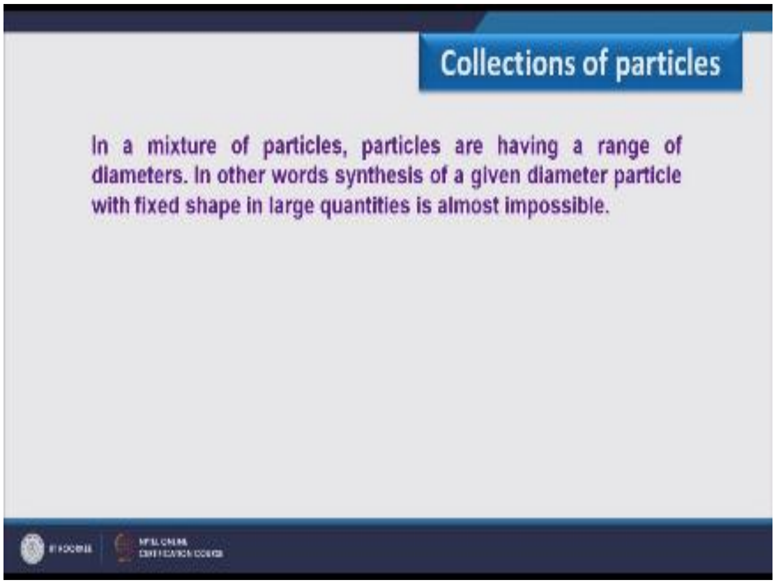

In a mixture of particles, particles are having a range of diameters, in other word synthesis of a given diameter particle with fixed shape in large quantities is almost impossible, therefore to ascertain the properties such as surface area, porosity, specific surface area, shape factor etcetera of the system of particles it is necessary that we should know the size and shape distribution of particles.

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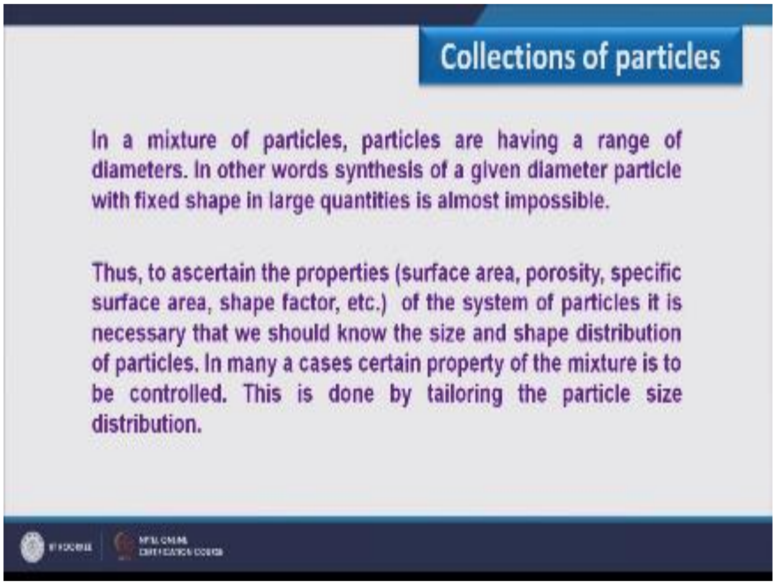

In many a cases certain property of the mixture is to be controlled, this is done by tailoring the particle size distribution.

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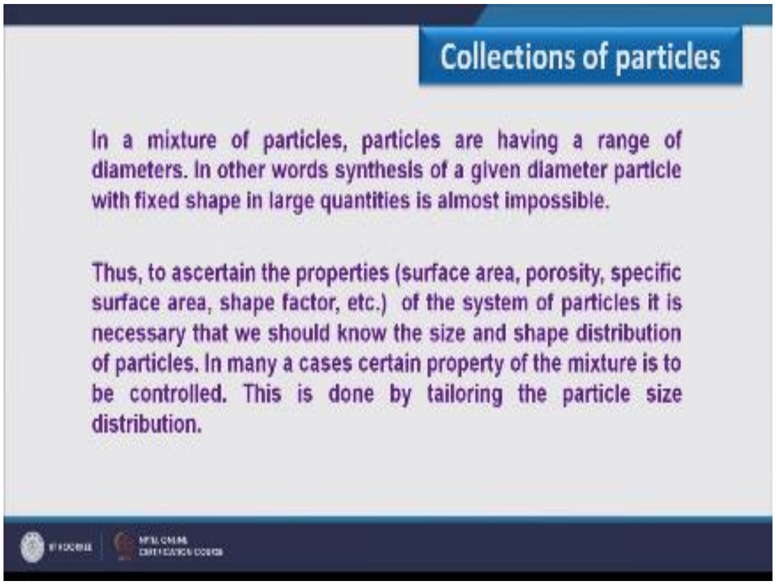

So the particles must be separated according to their size before using them for any industrial operation.

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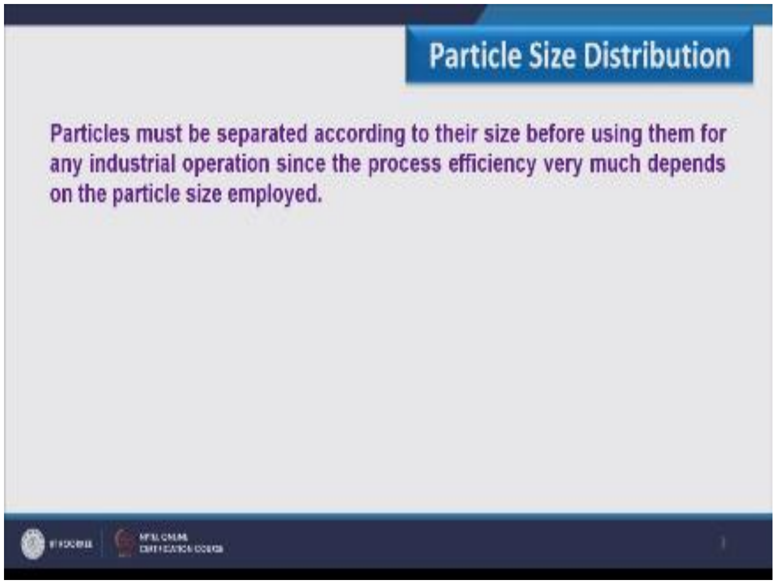

Since the process efficiency very much depends on particle size employed, if you remember the first lecture of this course that is the introduction where we have discussed that success and failure of the product depends on particle size, therefore to measure the particle size or to separate the particles according to their size is important for the industrial operations.

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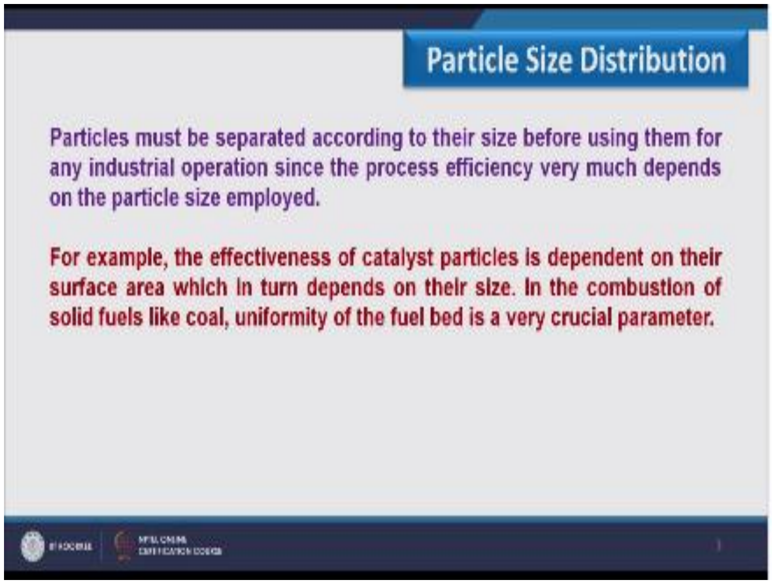

For example the effectiveness of catalyst particles is dependent on their surface area which in turn depends on their size; in the combustion of solid fuels such as coal uniformity of fuel bed is very crucial parameter. So you see the size is important as far as any application or as far as any industrial application is concerned.

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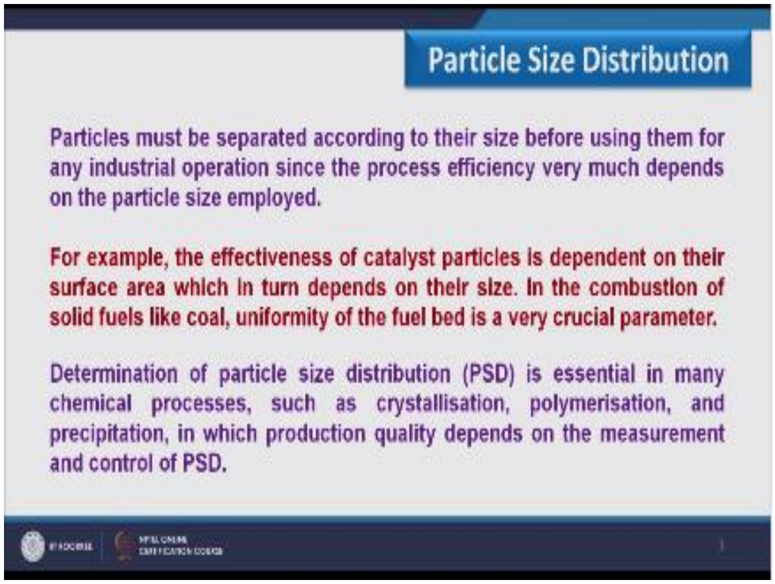

Therefore determination of particle size distribution is essential in many chemical processes such as crystallization, polymerization and precipitation in which production quality depends on the measurement and control of PSD that is particle size distribution. Particle size is determined by a number of methods such as.

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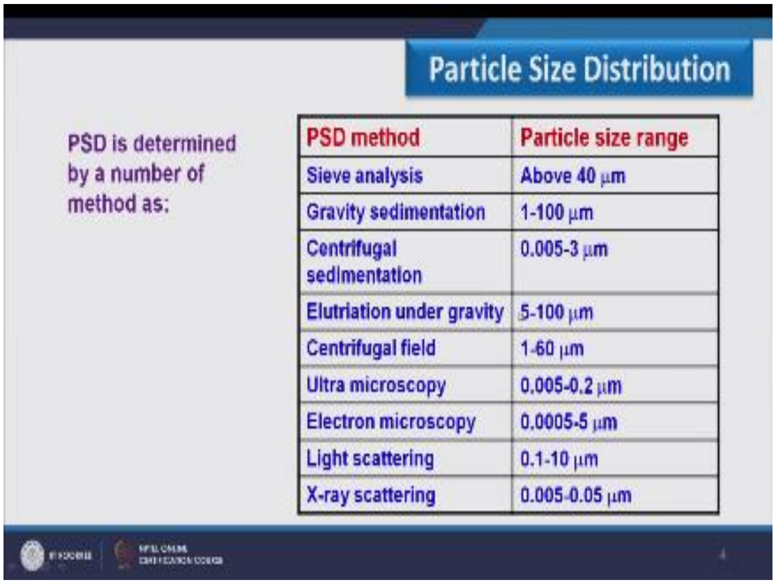

Here if you see this table in the first column we have PSD method by which different method we can determine the particle size and here I am having the particle size range measured by each method. So here if I consider sieve analysis it measure the particle size above 40 μm, gravity sedimentation 1 – 100 μm and so on we are having different methods. In this particular lecture we discuss sieve analysis to measure the particle size distribution, so from here onward what is sieve analysis and how particle size distribution will be done using this that we will discuss.

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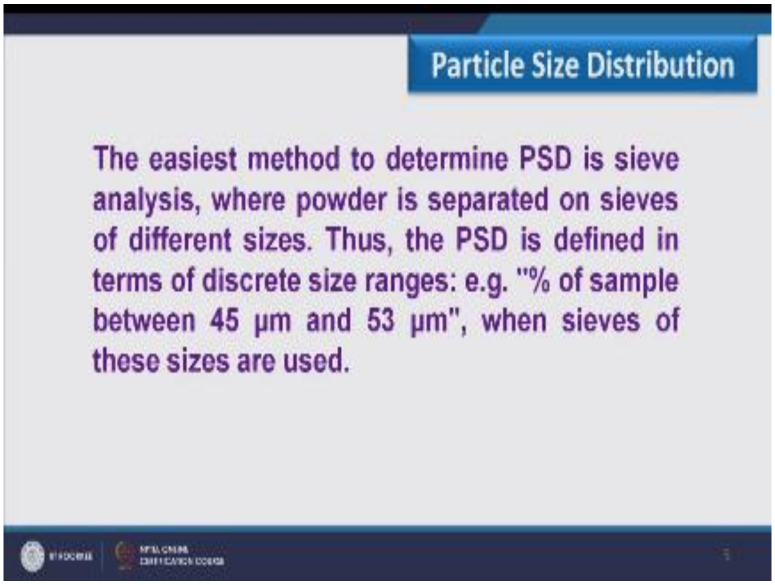

So the easiest method to determine PSD is sieve analysis where powder is separated on sieves of different sizes. Thus the PSD is defined in terms of discrete size ranges, for example percentage of sample between 45 μm and 53 μm, when sieves of these sizes are used. So here you see it is collection of particle on particular sieve we can obtain so it comes under discrete analysis.

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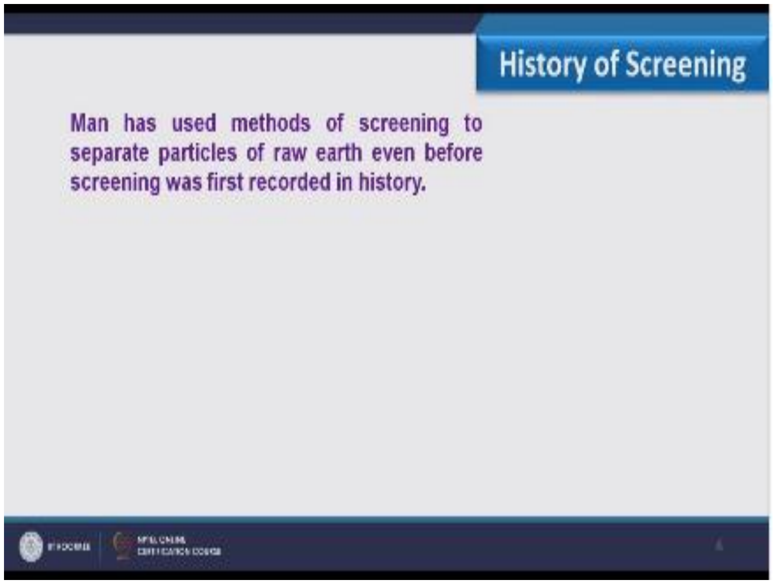

So here I am discussing the history of screening where whatever we have used in past days that I will show over here.

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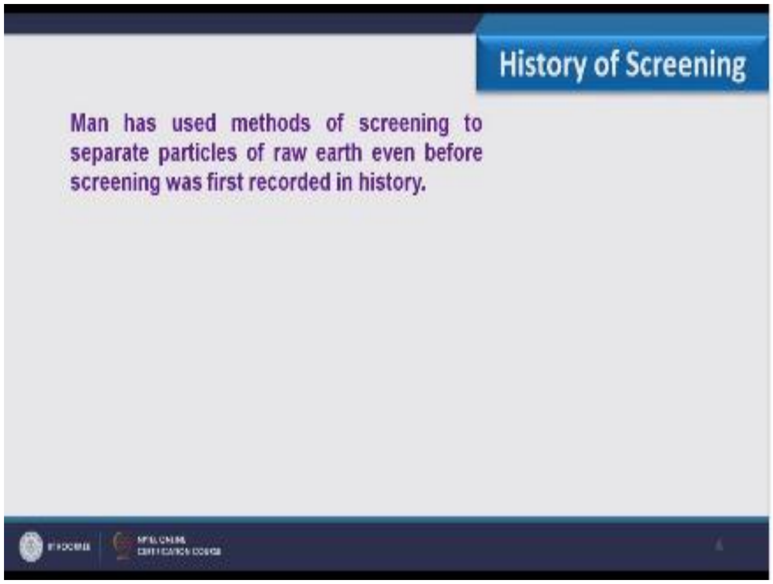

So man has used methods of screening to separate particles of raw earth even before screening was first recorded in the history.

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So if you see this figure it is the very old screen which I have also shown in introduction lecture, so it is the first recorded reference of screening dates back to 150 BC where Greeks and Romans described using crude sieves of woven horse hair for separating minerals and clays. So if you consider this particular screen it is made of horse hair, nowadays we use this screen made of metal.

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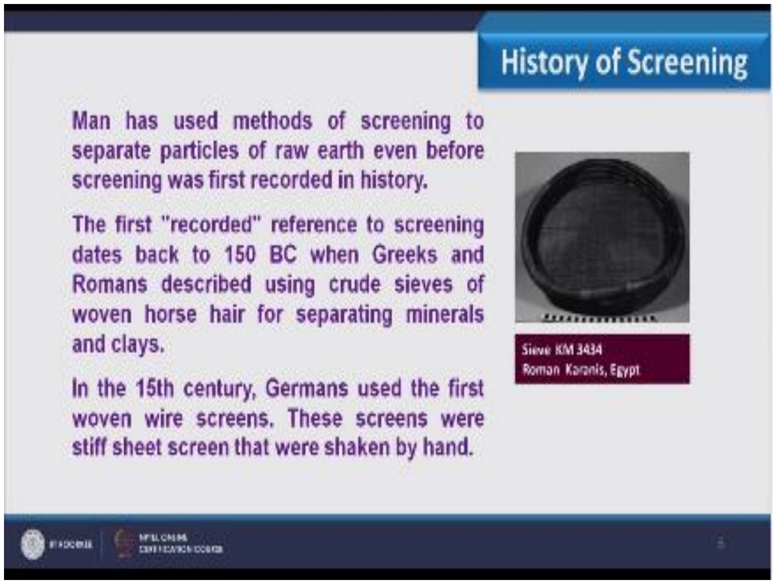

In the 15th century Germans used first woven wire screens, these screens were stiff sheet that were shaken by hand, so that is the history of screen. Now what is a screen and why, what I am calling as a sieve, if you see this figure from this figure you can understand very well.

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That what is a screen, here I am having this particular screen were we have the uniform opening at the base so the screening can be called as an open container usually cylindrical with uniformly spaced opening at the base as shown in this figure.

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It at the base of it we have uniformly spaced openings; it is normally made of wire mesh cloth, the wire diameter and the interspacing between wires being accurately specified. So depending upon this opening.

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The material which should be available over it or should be passed through it that we have to consider.

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Therefore if you see this figure it has different screen, if you see these two screen it has larger opening in comparison to this, so larger particle can pass through this and a smaller particle can pass through this. Along with this in this particular figure we have another container which has no opening at the base so we call it as a pan. So if you consider the screen it has three basic component, first is the screen itself.

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Second is the pan which is placed below to the screen and third we have the cover which place at the top of the screen so that during operation fines should not take off from the system.

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And in this figure if you see the, this particular component it is basically called scoop to feed the material at the screen.

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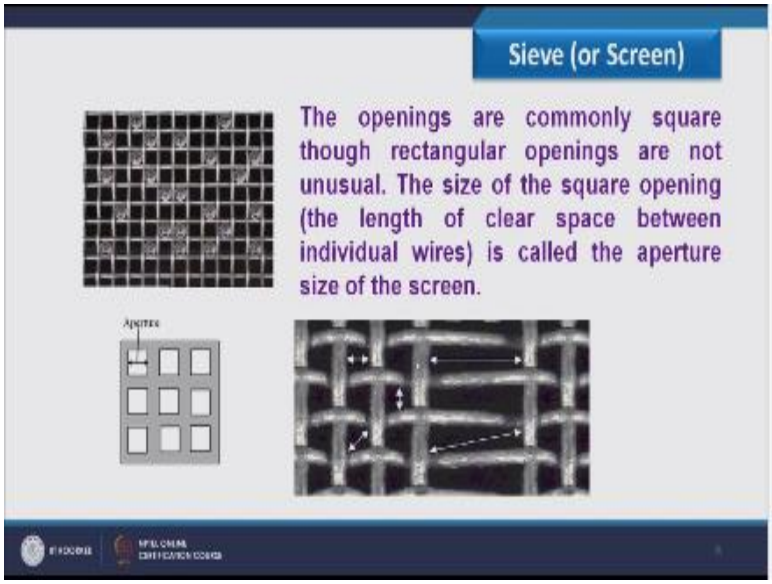

So the openings of a screen are commonly square through rectangular opening are not unusual, the size of the square opening that is the length of clear space between individual wire, if you see this figure it has the opening as I have shown over here also. So this particular square opening is called the aperture size of the screen, therefore depending on this particular size the material which should be passed through it can be decided.

And in this particular figure you see here somewhere I am having the square opening and somewhere I am having the rectangular opening, this we used when we are dealing with needle kind of or rectangular kind of material, for example if I want to screen the mica. So screens are usually designated by their mesh number, what is mesh number?

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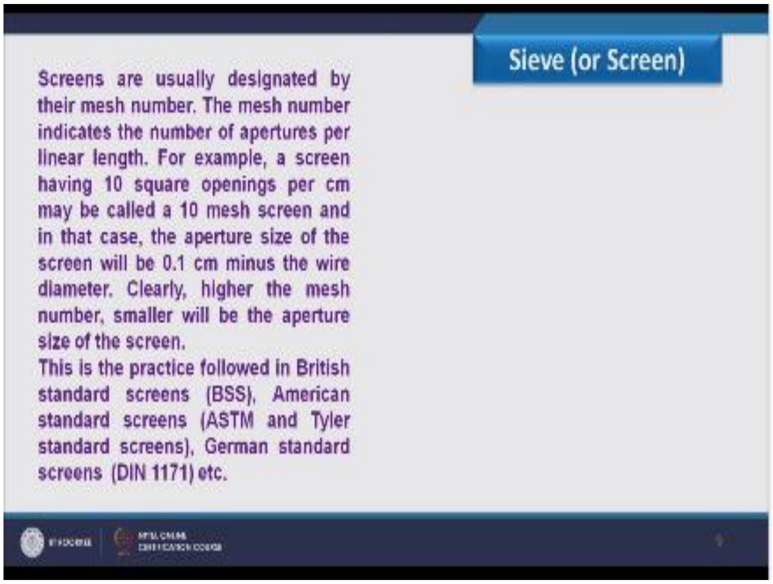

Mesh number indicates the number of apertures per linear length. For example if I consider in a screen 10 square opening so 10 would be the mesh number of that particular screen, so how we define the opening of that? Suppose I am considering linear length as 1cm and 10 mesh screen I am considering. So 1/10 that is 0.1 cm minus the via diameter would be the aperture size of the screen, so therefore higher would be the mesh number, smaller would be the aperture size of the screen because length would be uniform, that is 1cm. If I consider 100 mesh screen 1/100 so obviously aperture size will keep on decreasing as we increase the mesh number.

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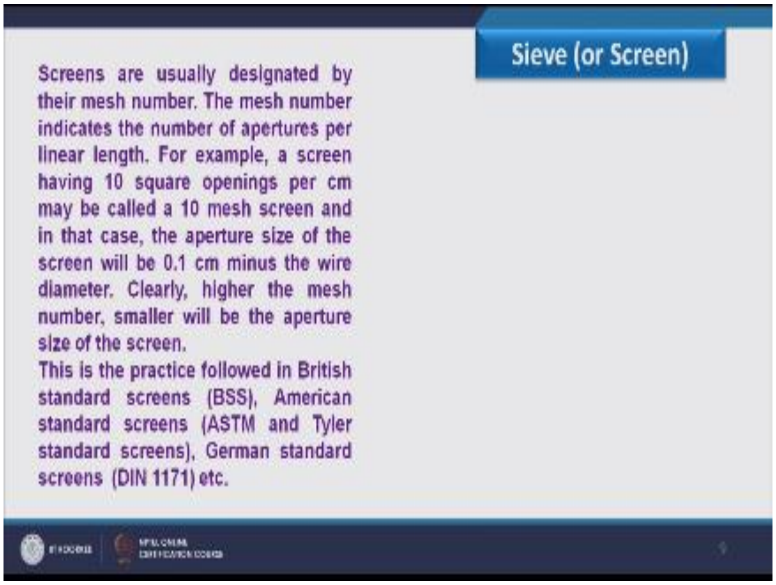

So this practice is followed in British standard screen, that we call (BSS), American standard screen(ASTM) and Tyler standard screens, German standard screen (DIN 1171) etcetera. So here what we have seen the mesh number, mesh number directly indicates the number of opening and using this mesh number we can calculate how much would be the aperture size of a particular screen.

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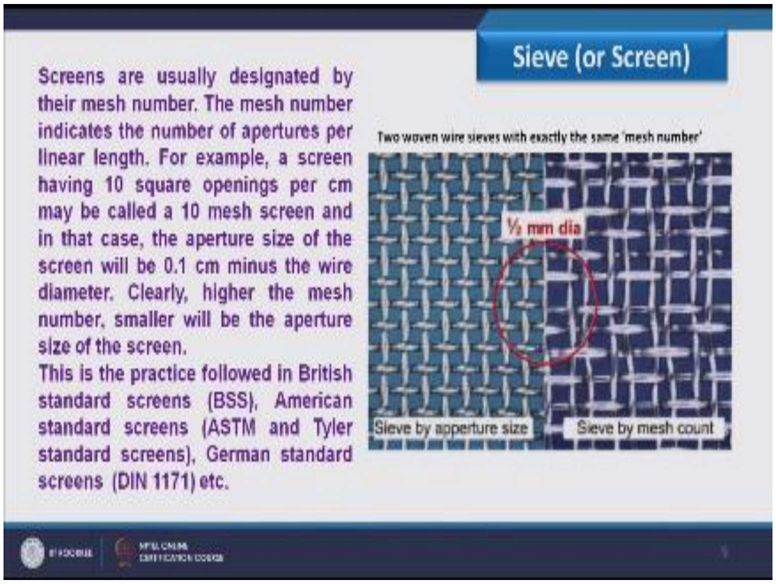

Now here I am showing one figure to show what is the effect of mesh number on aperture size? For example if I consider the left figure and in this figure you can see the aperture size is quite uniform, however the right figure shows aperture size is not uniform. In the left figure if I am considering this particular section where I am having four mesh, for example from here to here if I consider 1, 2, 3, 4, four openings.

So four mesh screen is there for example, here in the same length if I am considering so again 4, 1, 2, 3, 4, four mesh screen, so both are having four mesh screen. What is the difference between the two? If I consider only the mesh count it means both should screen same material but if you see the right figure some openings are larger some opening are smaller, so obviously material will not be uniform which will pass through this particular screen.

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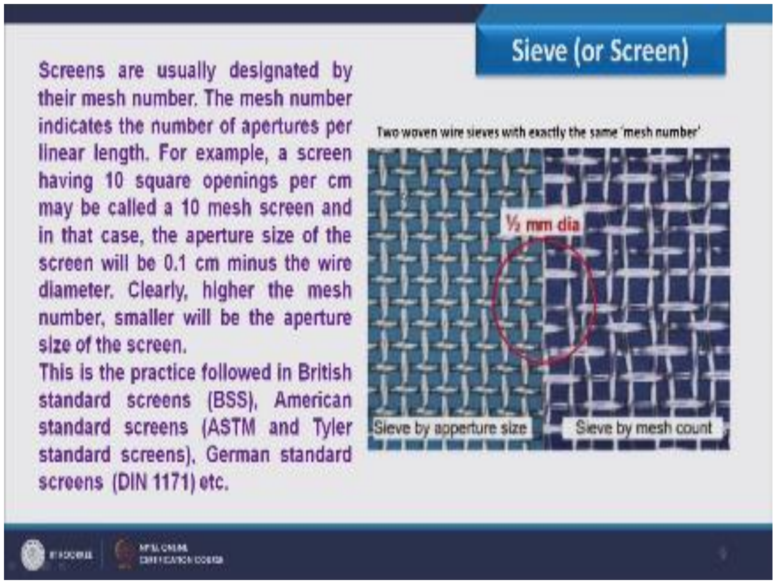

However if I consider the left screen it has all material of uniform size which will be passed through it. So this figure basically speaks about that instead of mesh number do I have any other representation to show the screen? The answer is yes.

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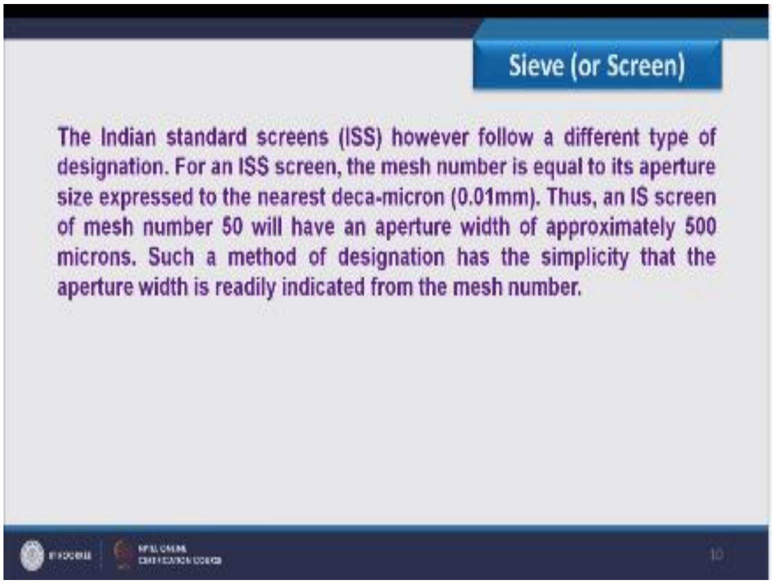

Therefore the Indian standard screens that is (ISS) however follow a different type of designation. For an ISS screen the mesh number is equal to the aperture size expressed to the nearest deca-micron, that is 0.01mm. So what Indian standard screen follow that we define a screen in terms of aperture size not as the mesh number.

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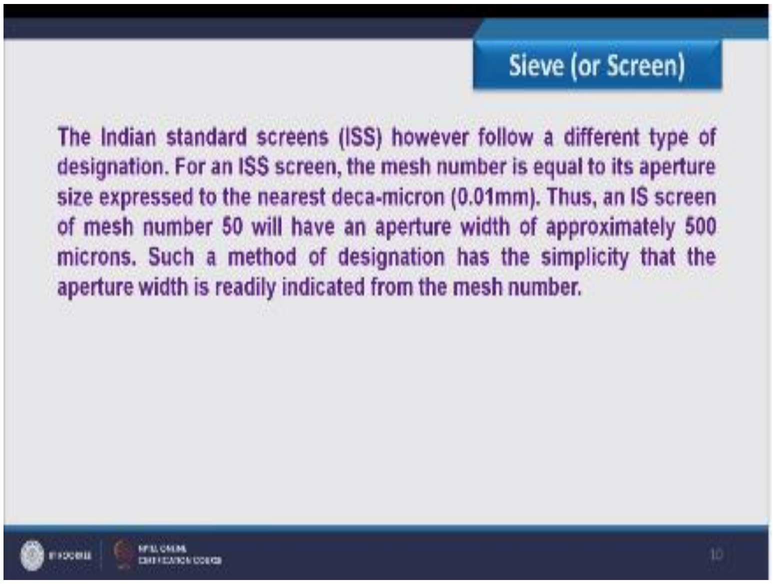

So that is the mesh number is equal to its aperture size expressed to the nearest deca-micron that is 0.01mm, therefore if I consider the screen of mesh number 50 the aperture size would be 50 x 0.01 mm that is 0.5mm which will convert into microns that would be 500 microns. So in this case as I am having increment in mesh number I will have more aperture size. So such a method of designation has a simplicity that aperture width is readily indicated from the mesh number.

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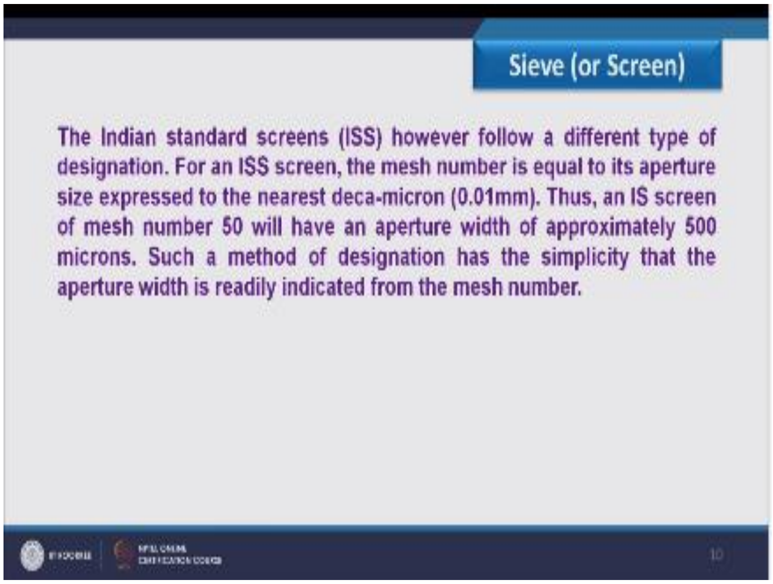

If I consider British standard or American standard it is quite opposite, for example if I having the more number of meshes or mesh number will increase, screen size will decrease so that is quite complicated to remember. However in Indian screen if I am having more number of meshes it has more aperture size.

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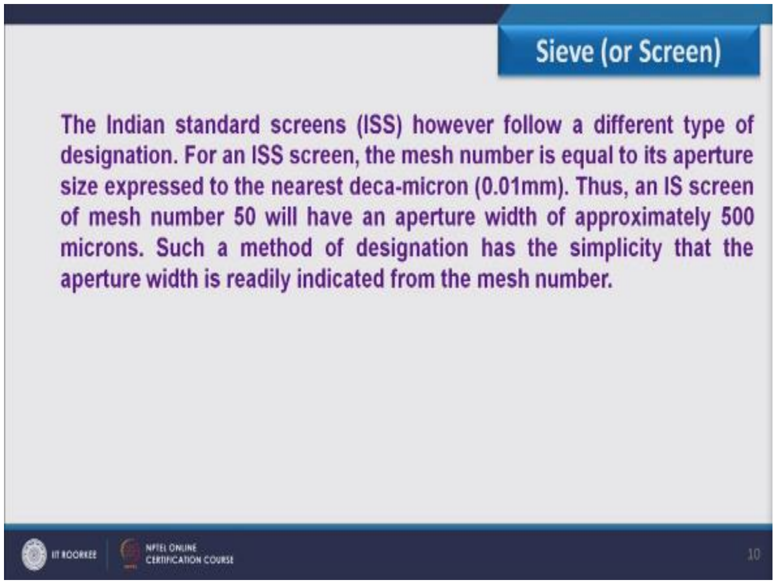

So it is easy to remember, so standard test screens.

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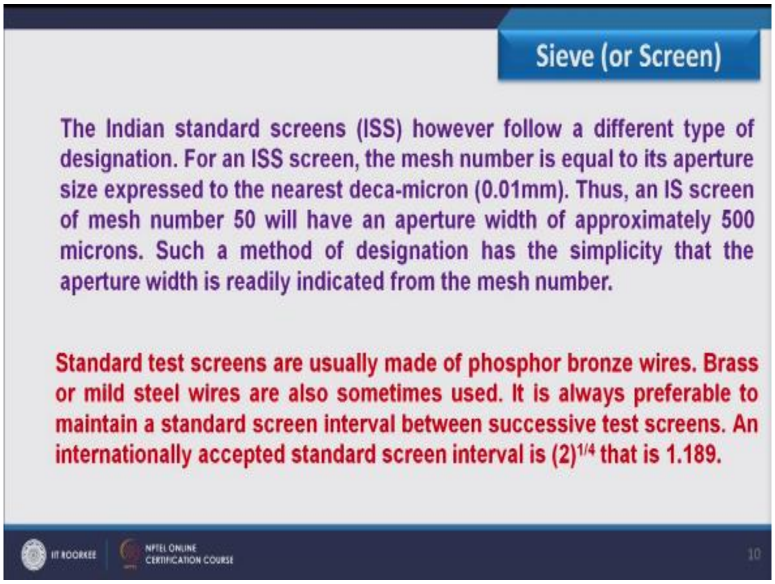

Are usually made of phosphor bronze wire. Brass or mild steel wire are also sometime used. It is always preferable to maintain a standard screen interval between successive test screen. An internationally accepted standard screen interval is $(2)^{1/4}$ that's I 1.189. So here you see this particular interval we follow between two successive screens, however sometimes we have some other standard also but usually we have $(2)^{1/4}$.

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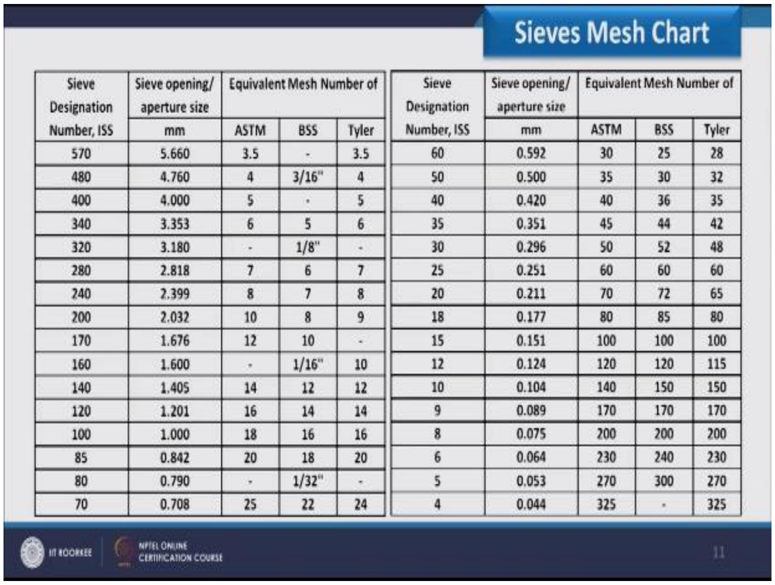
Sieves Mesh Chart

Sieve Designation Number, ISS	Sieve opening/ aperture size mm	Equivalent Mesh Number of ASTM	BSS	Tyler	Sieve Designation Number, ISS	Sieve opening/ aperture size mm	Equivalent Mesh Number of ASTM	BSS	Tyler
570	5.660	3.5	-	3.5	60	0.592	30	25	28
480	4.760	4	3/16"	4	50	0.500	35	30	32
400	4.000	5	-	5	40	0.420	40	36	35
340	3.353	6	5	6	35	0.351	45	44	42
320	3.180	-	1/8"	-	30	0.296	50	52	48
280	2.818	7	6	7	25	0.251	60	60	60
240	2.399	8	7	8	20	0.211	70	72	65
200	2.032	10	8	9	18	0.177	80	85	80
170	1.676	12	10	-	15	0.151	100	100	100
160	1.600	-	1/16"	10	12	0.124	120	120	115
140	1.405	14	12	12	10	0.104	140	150	150
120	1.201	16	14	14	9	0.089	170	170	170
100	1.000	18	16	16	8	0.075	200	200	200
85	0.842	20	18	20	6	0.064	230	240	230
80	0.790	-	1/32"	-	5	0.053	270	300	270
70	0.708	25	22	24	4	0.044	325	-	325

This particular slide shows or sieves mesh chart where you see here I am having the sieve designation number as per Indian standard and here corresponding opening is shown and equivalent mesh number of ASTM, BSS Tyler are shown over here, so here you can see very well that as we decrease the mesh number from 570 to 70 in Indian standard screen aperture size will keep on decreasing however the mesh number will keep on increasing, that is just opposite to the Indian standard.

So here we have the sieve from 570 to 70 then again from 60 to 4 and correspond to 4 the value is 0.044 so that is 44 microns. So if you remember the pervious slide sieve analyses gives the particle size distribution up to 40 microns or above to this, so this screen vary from 572 4 mesh number.

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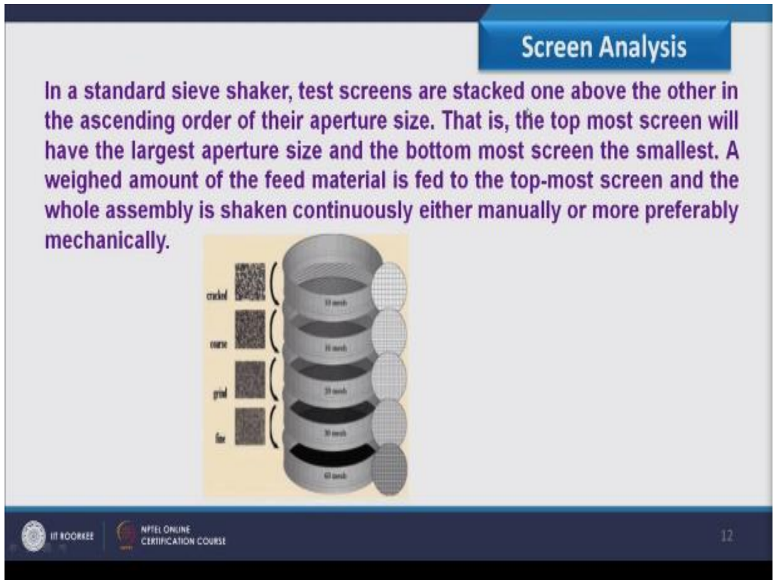

Now what is sieve analyses? sieve analyses is basically done using standard sieve shaker in which screens of different sizes are arranged one over another. In this test screens are stacked one above the other in the ascending order of their aperture size. If you see the top most screen it has the largest size because it has to retain the largest size particle and has to pass the practical lesser than this so therefore the largest opening screen is placed at the top and finest opening screen should be placed at the bottom.

Now below the finest opening screen we should place the pan and over the largest opening screen we should place the cover, so the cover different size of the screen and the pan will give the complete assembly of screen analyses. So here how we do the screen analyses, once this complete assembly is ready weigh the feed and that feed we keep at the top most screen and complete assembly.

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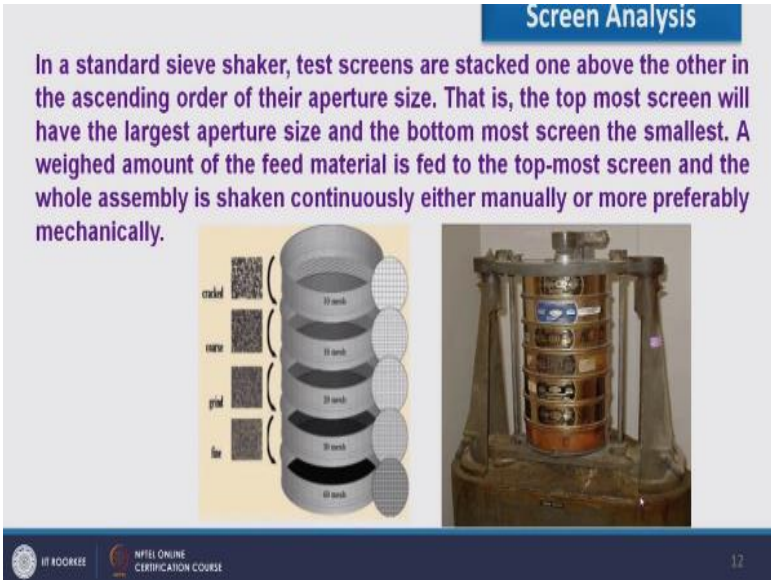

Is put into the shaker, this is basically the shaker here, you see this particular assembly it mechanically vibrates this particular set. So as for as movement is concerned it has gyratory motion, it has oscillatory motion and along with that it has the vibratory motion. How the vibratory motion is done? If you see that top most assembly it has a hammer kind of structure which keeps on hammering this particular set from the top so that the material which is clogged in between the screen that should be passed through the screen.

So here I am having gyratory, oscillatory and vibratory motion when we put this screen into the shaker. So after some time the complete feed which we have put at the top most screen should be distributed in these particular screen and whatever is passed from the finest opening screen is collected at the pan, therefore in this schematic I have shown what will happen.

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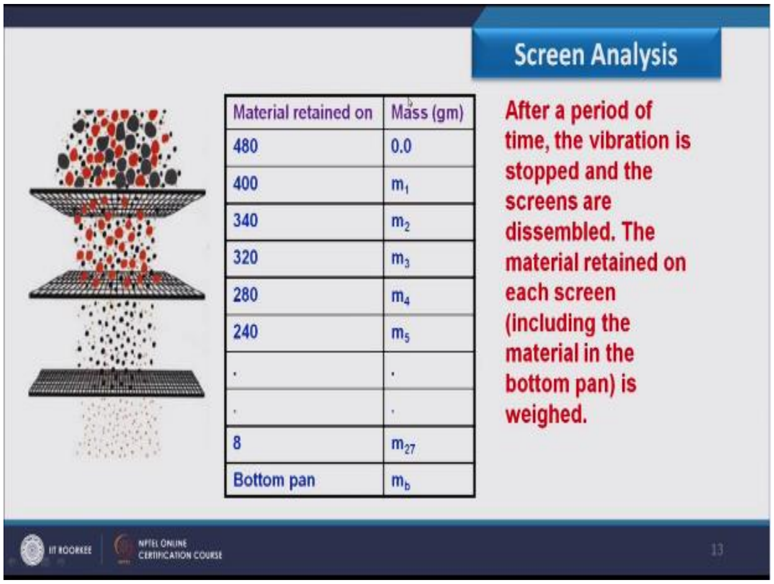

So if you see this particular screen it has largest opening and the, this particular screen has the smallest opening and material is distributed according to their size. So obviously top most has the coarsest material and below the finest we have the finest material which is collected at the pan.

So after a period of time the vibration is stopped and the screens are dissembled, the material retained on each screen including the material in the bottom pan is weight, so here if you see this in this way we represent the data of particle size which we have obtained from different screen. So here you see at 480, 0 mass is available however at 400 we have m_1 mass and accordingly whatever mass is collected in different screen as well as pan that we have noted down in this table.

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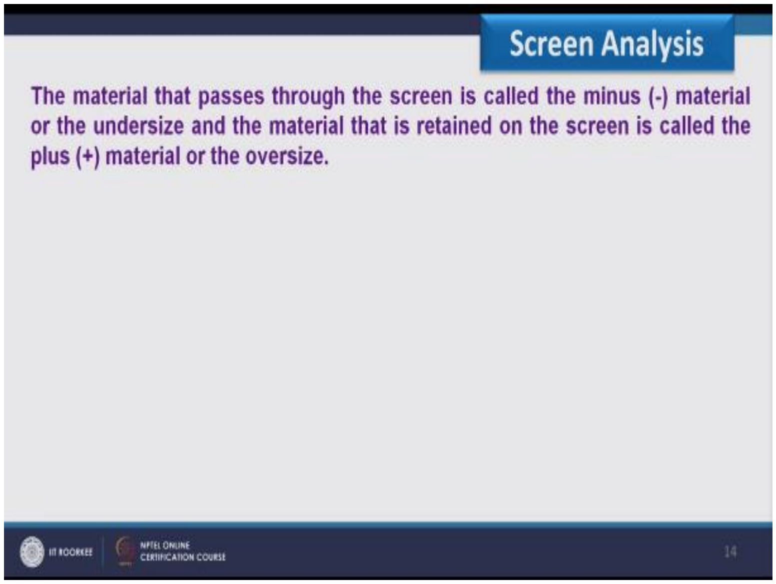

So material that passes through the screen is called the minus material which we also call as undersize and the material that is retained on the screen.

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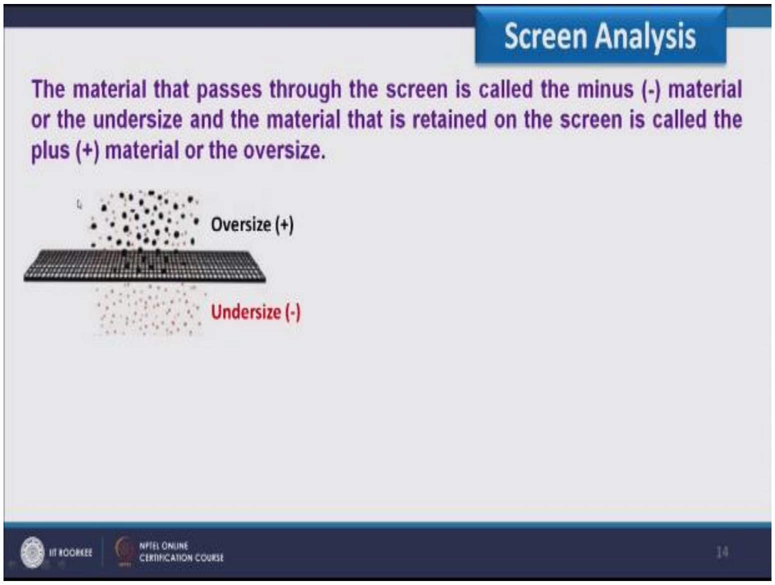

We call it plus material that is the oversize. So if I am having this particular screen whatever is available at the top that we call oversize and whatever is passed through it that we call undersize or minus, so while representing the data we will use two signs first is minus and second is plus. Minus shows material which is passed through the screen and plus shows material which is retrained on the screen.

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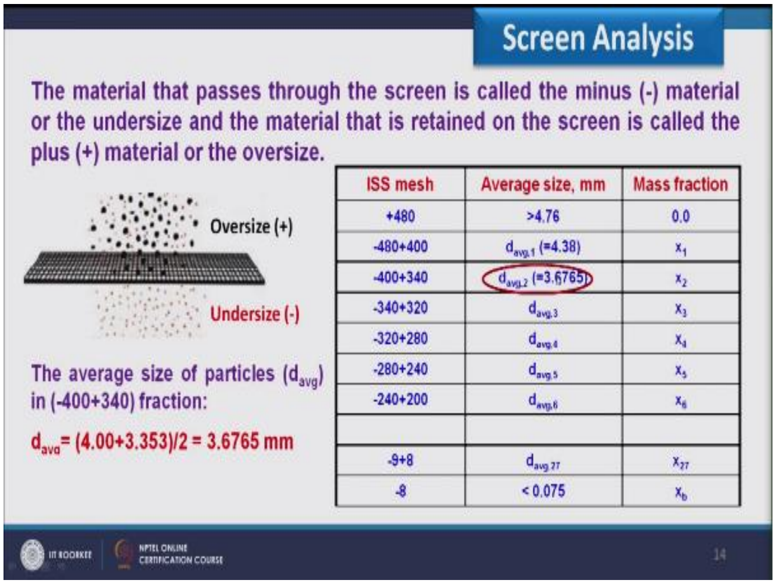

In this form we represent the complete data like if I consider this +480 mesh it means material which has to be retained on it that we have to represent over here which is in this case is 0. It has size greater than 4.76, how this value we have obtained, by referring the standard sieve chart. Therefore, if I considered the second data of this that is -480 +400 here you see the material which is passed through 480 and retained on 400 mesh screen we can write in this manner -480 +400 and its fraction is x_1.

What is this d_{avg} how we calculate this d_{avg} is the arithmetic mean of size correspond to 480 and 400 mesh. The average size of particle d_{avg} is -400 +340 fraction we have shown over here correspond to 400, the size is 4mm correspond to 340 mesh we have size 3.353, if we take the arithmetic mean the value 3.6765 mm would be the d_{avg} or would be the size of material which is available at the screen. And whatever fraction is there that is how we can compute this that is very simple total mass which is available.

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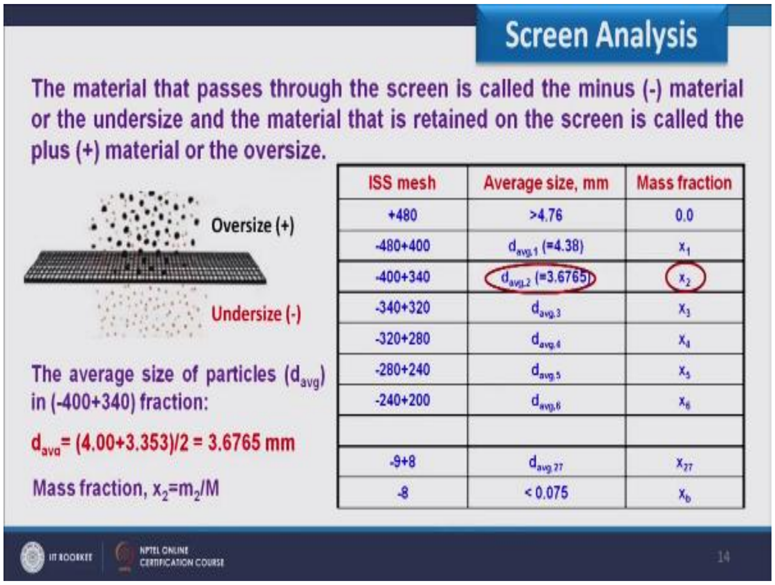

On that screen divided by the total mass which we have fed to the screen, topmost screen. Therefore, in this way we can represent the data of a screen analysis which includes mesh number.

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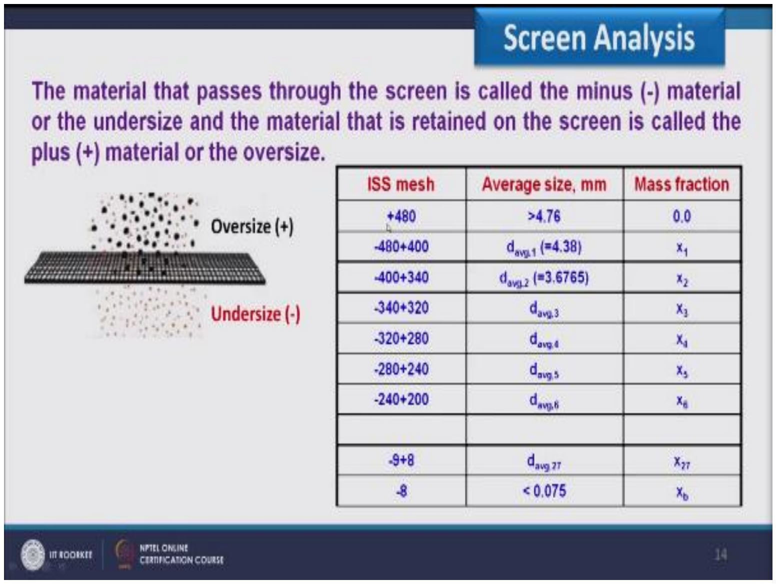

Average size and mass fraction of the material. Considering this we can derive the expression for a specific surface area of mixture of particle. For example, if I consider i^{th} fraction.

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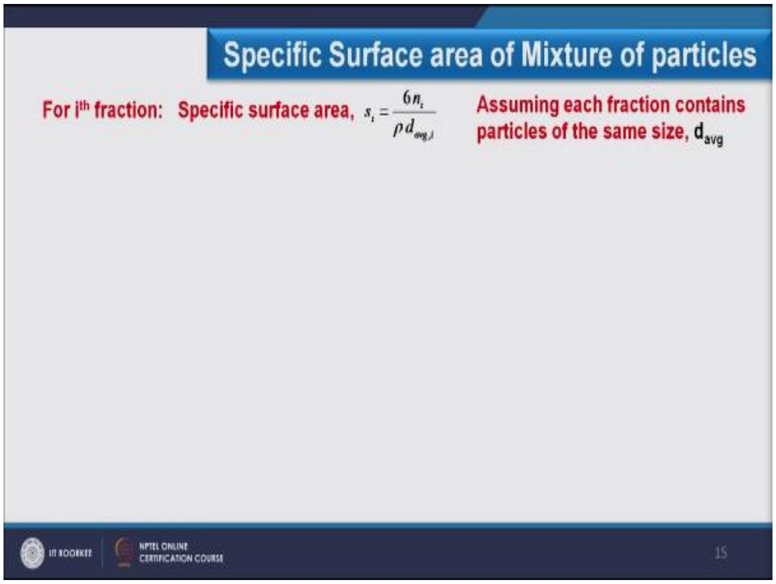

Specific surface area can be denoted by this that is $s_i=6n_i/\rho d_{avgi}$ this is a specific surface that is surface area per unit mass of the mixture, and if you remember this particular expression this we have discussed in lecture 3 where we were discussing specific surface ratio. Now in this i^{th} fraction I have considered $d_{avg,i}$.

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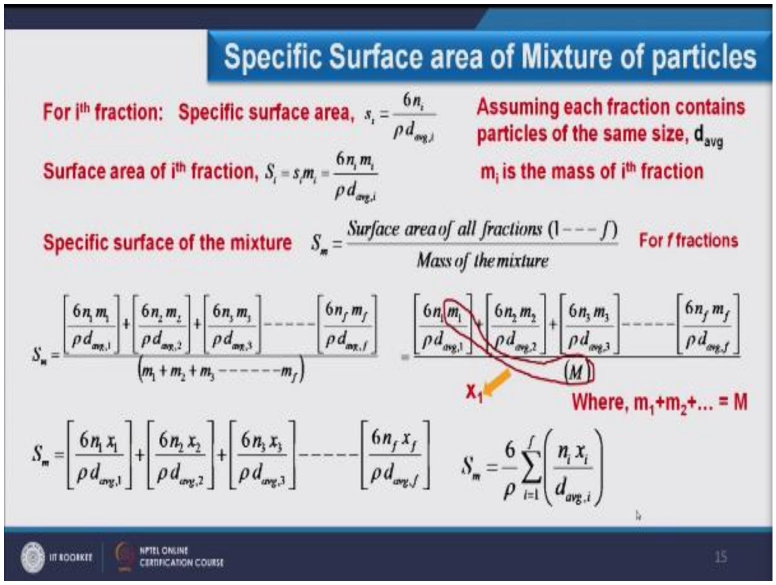

And during this we have assumed that this particular fraction or similarly other fraction contains particles of same size that is $d_{avg.}$ So surface area of i^{th} fraction how we can compute this, that is we have denoted with S_i so that would be small s_i that is nothing but this into total mass available in i^{th} fraction. So that is $6n_i m_i / \rho d_{avg,i}$ where m_i is the mass of i^{th} fraction. Specific surface area of the mixture is, we have denoted this with S_m it is equal to surface area of all fraction 1 to f / mass of the mixture where I am considering total f fractions. So this is the expression where this particular expression $6n_i m_i / \rho d_{avg,i}$ we have written for each fraction and similarly we have counted the mass of each fraction to calculate total mass.

So this m_1 to m_f can be represented by M, now if I consider a small m_1 and M that we can write very well with $x_{1,}$ that we can represent with x_1, so finally I am having this expression for f number of fraction if we want to write this in a generalized form that is $S_m=6/\rho$, because $6/\rho$ is common in all because we are dealing with same material so density would be uniform, and here we have a summation where i move from 1 to f, $n_i x_i / d_{avg,I}$ this is the expression for surface area of mixture of particles. In the similar line we can derive an expression to calculate.

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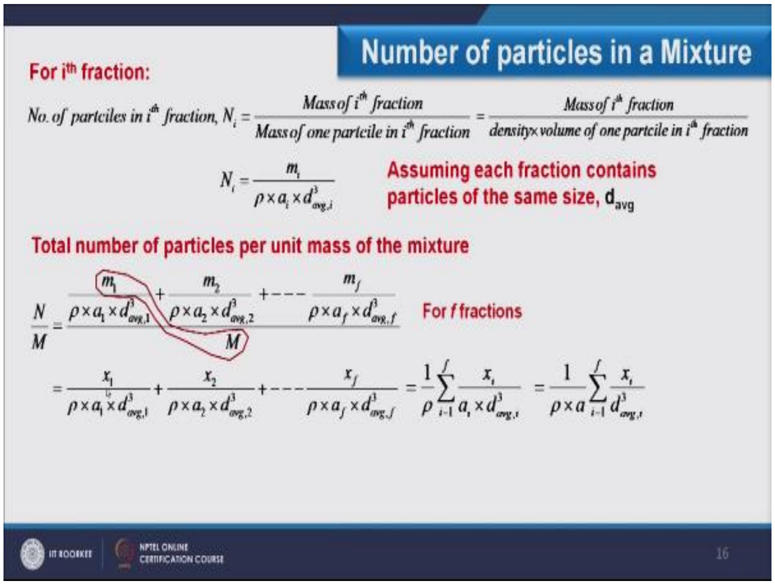

Number of particles in a mixture, for example if I am considering i^{th} fraction the number of particles in i^{th} fraction denoted as N_i = mass of i^{th} fraction / mass of one particle in a i^{th} fraction. Further mass of one particle in i^{th} fraction can be written as density x volume of one particle in i^{th} fraction. Numerically N_i can be shown as m_i that is mass available in i^{th} fraction / ρ x a_i x $d^3_{avg,i}$ $d^3_{avg,i}$ x a basically show the volume of a particle where a_i is the volume shape factor.

For this you have to refer lecture 3 of this course. Now for this particular fraction we can calculate number of particles so total number of particles per unit mass of the mixture we can write as N/M that is the total mass fed to the screen and here we are having different fraction. For one for first fraction it is $m_1/ \rho a_1$x $d^3_{avg,1}{}^3$ and similarly we can represent for other fractions also. and here we have total f fraction, all these values will be divided by M. So similarly if you remember the last slide m_1 and N we have represented as x_1, so if I represent the expression in terms of mass fraction.

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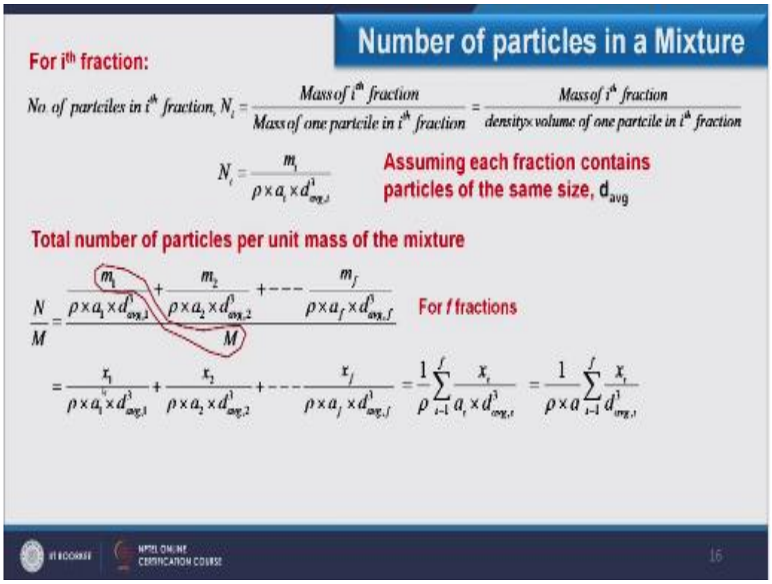

That would be $x_{1\ /}$ row x a_1x $d_{average1q}$ and similarly we can represent for other fractions also. In generalized form we can write 1/ ρ and ∑ of f fraction where I vary from 1 to f and the expression is xi/ a_i x d $_{average\ iq}$. If I am considering all particle of same shape then ai would be common so 1 ρ row x a∑ x_i $_{d\ average\ i}{}^{3}$ where I vary from 1 to f, this is the expression to calculate number of particles in the mixture.

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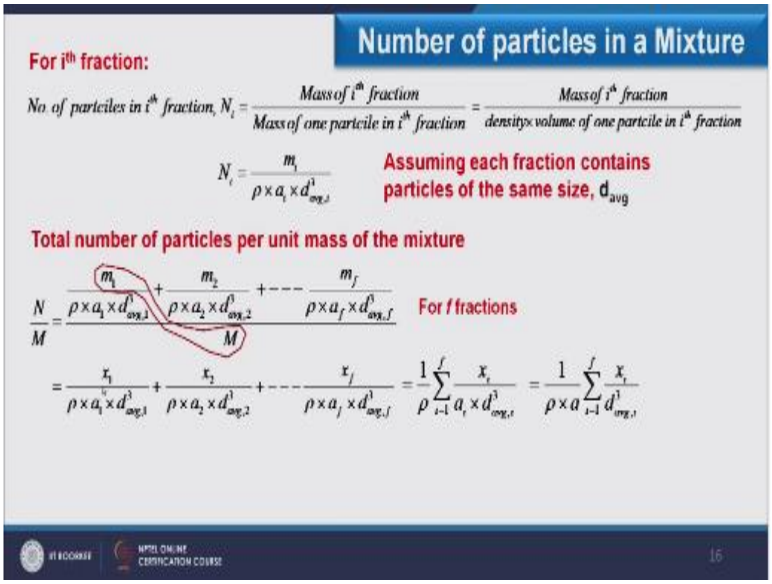

For constant shape of all particles, so once I am having this particles size distribution I can calculate specific surface area as well as.

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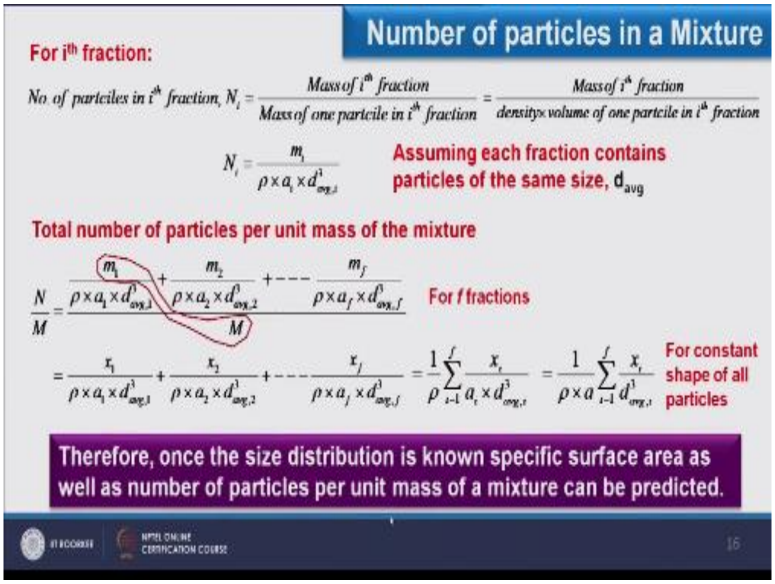

Number of particles per unit mass of the mixture and considering these expression we will solve one problem in next lecture. Further I am having measures to calculate the mean particle size of a mixture, if you remember the d average what is d average is the particle size of a particular fraction. If I want to calculate the particle size of complete mixture how we can calculate this?

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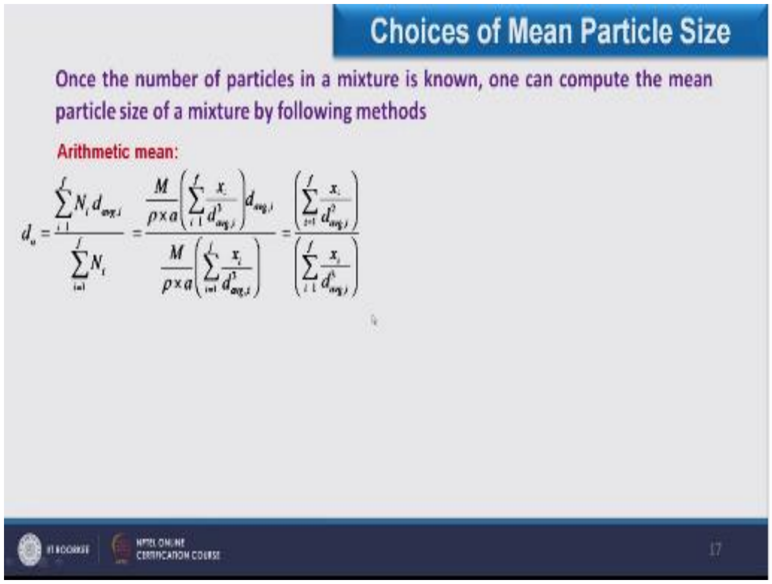

Now once the number of particles in a mixture is known one can compute the mean particle size of a mixture by following method. The first method is the arithmetic mean, we can write, we can compute the arithmetic mean of a mixture by this expression that is $\sum N_i$ d $_{avg}$ i / $\sum N_{i.}$ It means It number of particles x $_{avg}$ diameter of all fraction divided by number of particles in all fractions. If we write the expression of N_i we can have the complete expression in this form, once I resolve this as all these value will be cancelled out, once I resolve it the final expression of arithmetic mean would be $\sum$ I 12f xi d $_{avg\ i2}$/ $\sum$ i1to f xi/d $_{avg\ i3.}$

So this is the expression for arithmetic mean, in the similar line we can have the quadratic mean, we also call it as.

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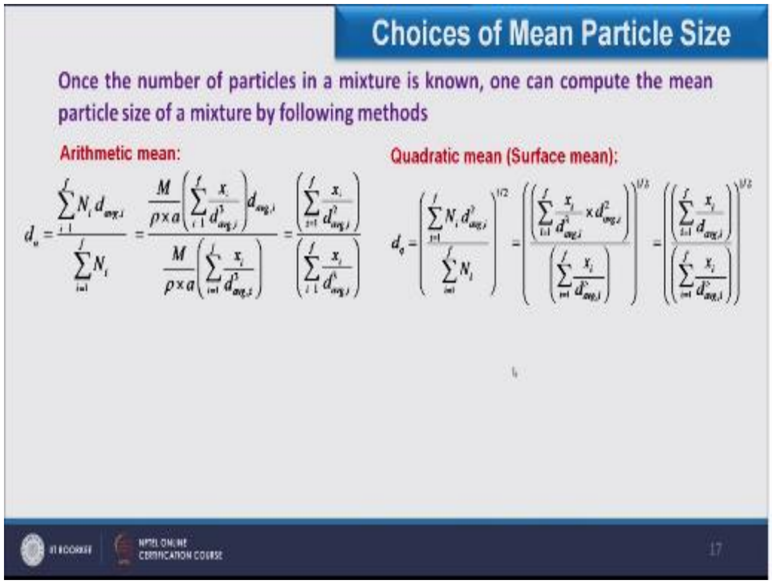

The surface mean diameter, so quadratic mean diameter that is N_i d average i^2 /N_i for all fraction this power ½. If I put the expression for Ni and further resolve it we can have d_q that is quadratic mean as ∑ i1tof x_i over d average i/ ∑ i1to f x_i d $_{avg\ i3}$ / ½. Further I am having the diameter as cubic mean or we also call it volume in diameter that is.

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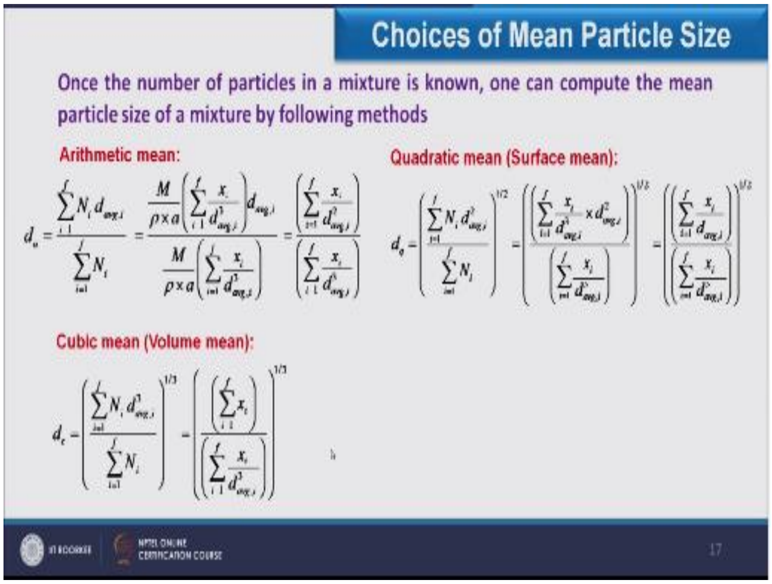

d_c and here we have the expression $N_i\ _{d\ avg}\ i^3$ /N_i power1over 3 writing the expression of N_i and resolving it the final expression I am having is ∑ i1tof x_i /∑ i1to f x_i over d $_{avg\ i3}$ 1/3, so all these three methods are used to calculate the mean particle size of a mixture.

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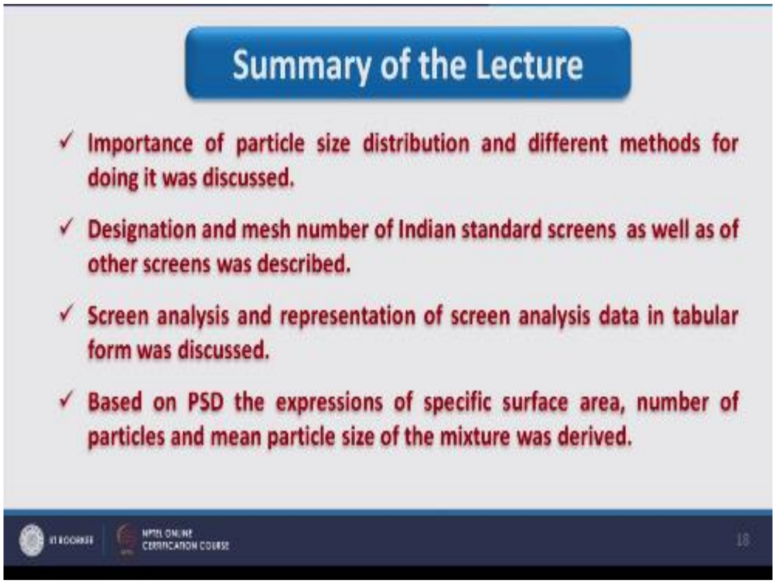

And here I am having the summary of this lecture. The importance of particle size distribution and different methods for doing it was discussed in this lecture; secondly the designation and mesh number of Indian standard screens as well as other screens was described. Screen analysis and representation of screen analysis data in tabular form was discussed and finally based on PSD that is particle size distribution the expressions of specific surface area, number of particles and mean particle size of a mixture was derived, so that is all for this lecture, thank you.

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