INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Mechanical Operations
Lecture-12
Examples of Laws of comminution-1

With
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Welcome to the second lecture of week 3 which is on examples of laws of comminution. This lecture 2 where I am discussing different example, it will have two different part, in part 1, I will consider two examples and in part 3 I will consider three examples. So total using five different example I will demonstrate how to calculate the power consumption in comminution process using three laws of comminution.

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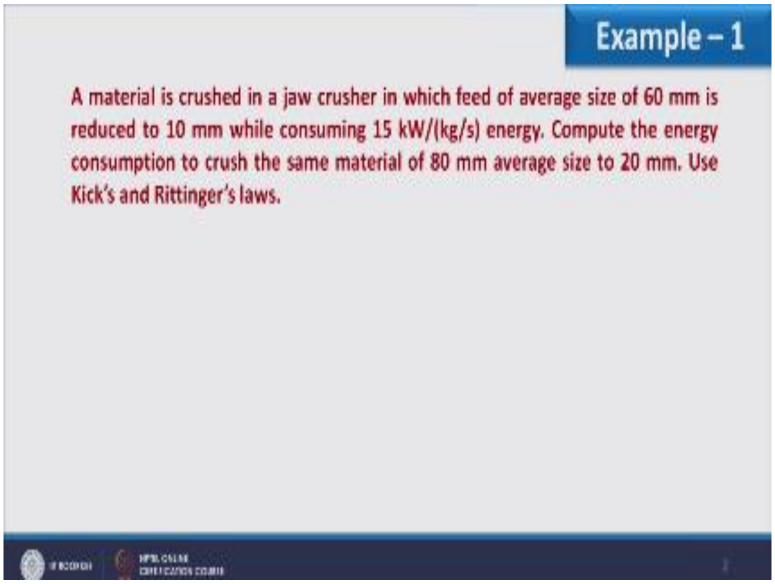

Example 1, in this example we have considered a problem where a material is crushed in a jaw crusher in which feed of average size of 60 mm is reduced to 10 mm while consuming 15 kW/(kg/sec) energy. So we have feed of 60 mm and product of 10 mm and while crushing we are using 15 kW/(kg/sec) energy.

Now what we have to compute the energy consumption to crush the same material of 80 mm average size to 20 mm. Further we have to calculate energy consumption for crushing same material and the energy consumption will be computed using Kick's as well as Rittinger's law.

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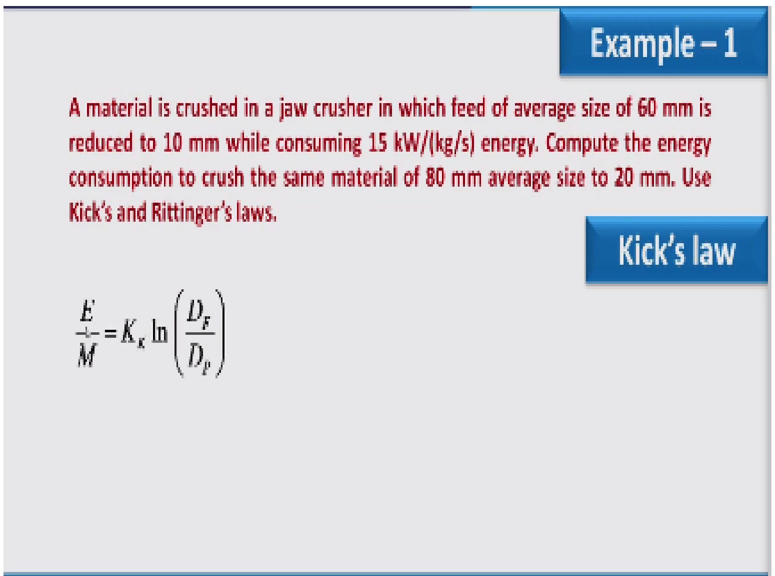

Let us start the computation first using Kick's law. So as you are very well aware with the expression of Kick's law and it is basically E/M that is energy consumption for crushing M unit of material. It is equal to K_K that is Kick's constant ln D_F/D_P. So here we have, if you see the first part of this question, here we have already given the energy consumption that is value of E/M is already known to us.

And it is equal to K_K ln D_F/D_P. So in first case D_F would be 60 mm and D_P would be 10 mm.

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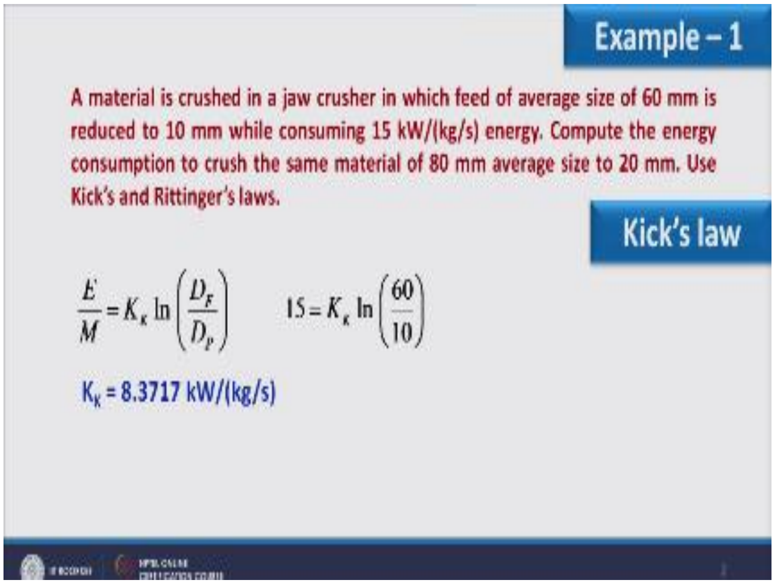

So once we use these value in the expression so E/M is replaced with 15 = K_K ln 60/10. And while after resolving it we can calculate the value of Kick's constant which comes out as 8.3717kW/(kg/sec). So here you see the unit of Kick's constant is equal to that of energy in the present case because that diameter is in the ratio form, so unit will be equal to as of that of energy.

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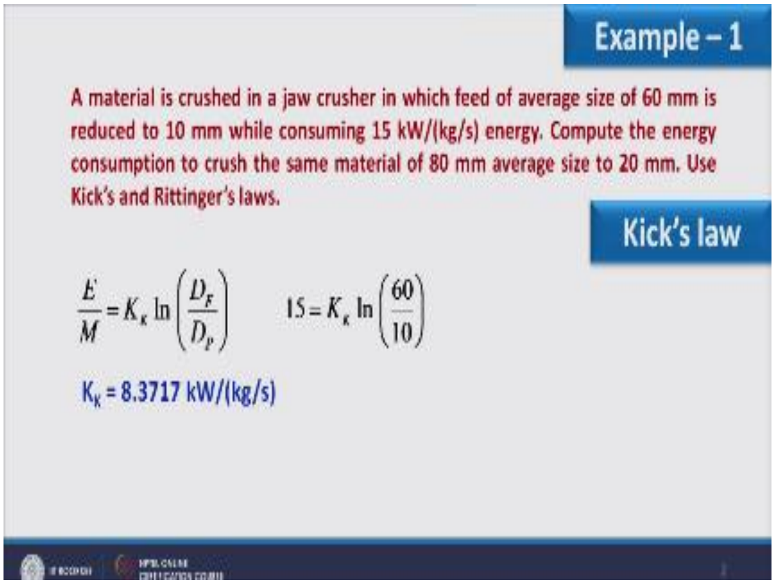

Once I am having the value of Kick's constant I can use this value of Kick's constant to calculate energy consumption while crushing material from 80 mm average size to 20 mm size. Now why we are using same Kick's constant, because material for which I am calculating the energy consumption is same.

However, its feed as well as product size will change and therefore, we can utilize the K_K which we have calculated here as 8.3717 that we can use.

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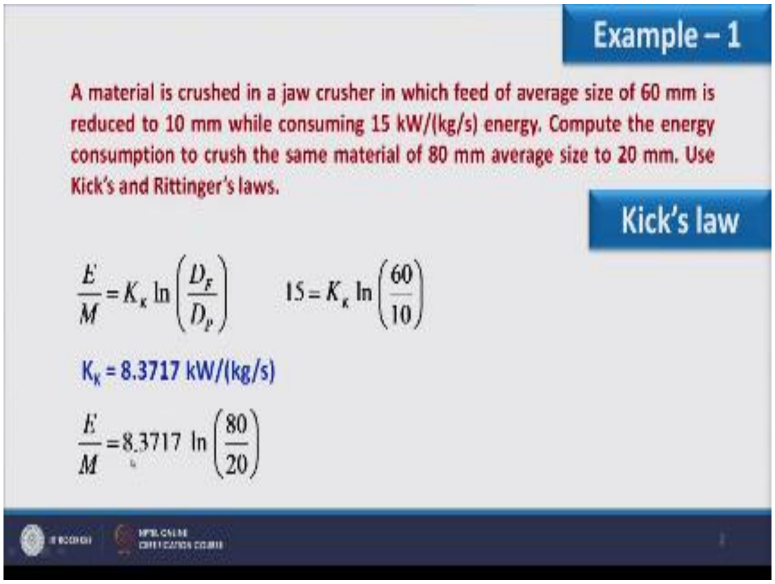

So finally we have E/M which we have to compute equal to Kick's constant value that is 8.3717 ln 80/20.

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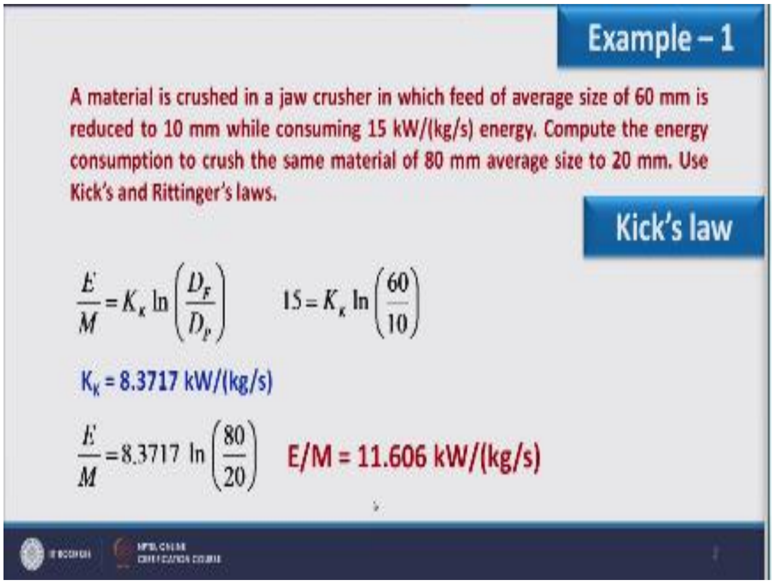

So using these value we can calculate energy consumption per unit of feed handled. So the value comes as 11.606kW, and here if you see the expression and if you see the value it varies from 60 mm to 10 mm and 80 mm to 20 mm. So it comes under coarse crushing where Kick's law is applicable. However, in the present example the same problem we have to solve using the Rittinger's law.

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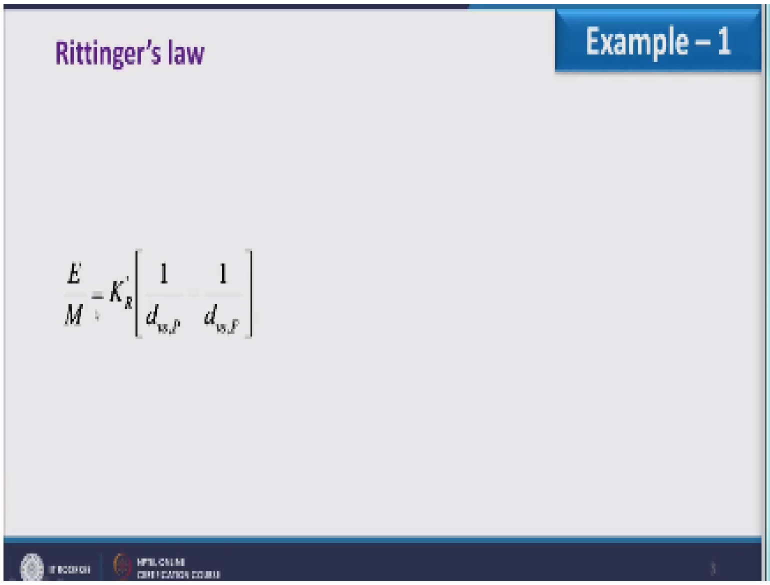

Now as far as Rittinger's law is concerned this is the expression of Rittinger's law where $E/M=K_R'[1/d_{vsp}-d_{vsf}]$. So here you can understand that when we have discussed Rittinger's law in lecture 1 of week 3 there we have represented this in terms of specific surface of product as well as feed.

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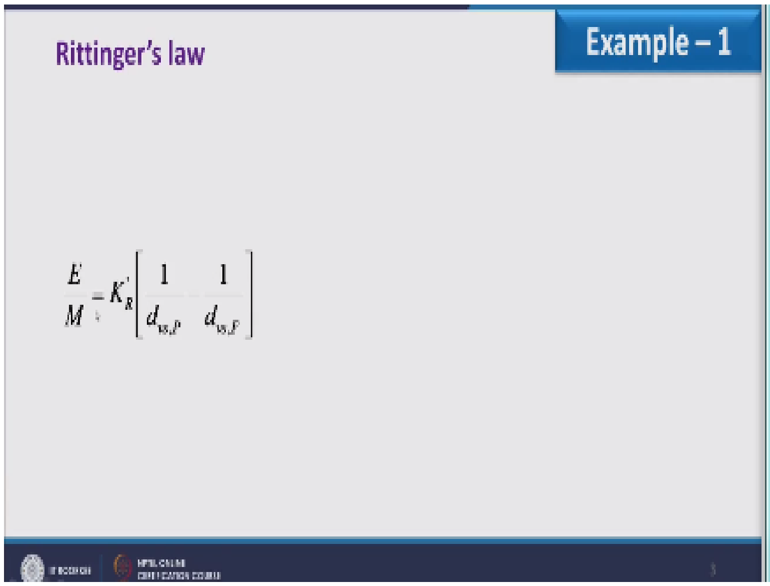

And in terms of this d_{vs} that is sorter diameter which is the volume surface mean diameter. And in this particular example as we are given the feed we are not given the distribution.

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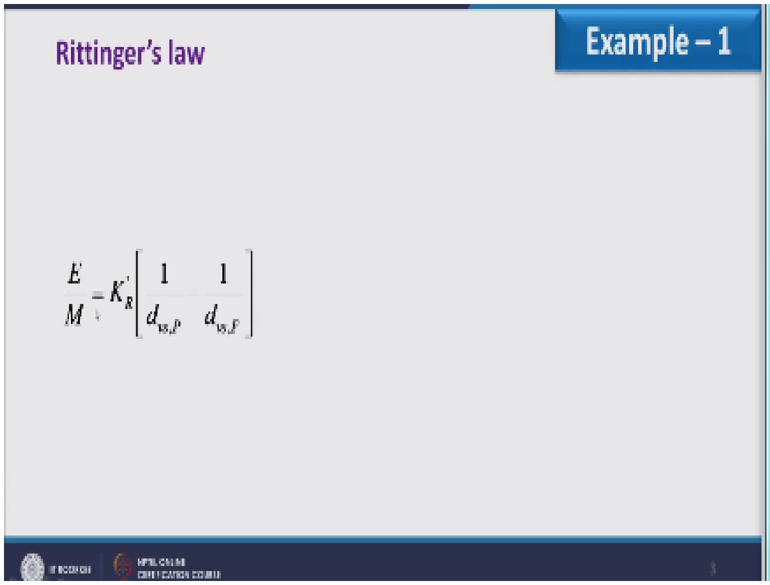

Therefore we cannot use the Rittinger's law in terms of specific surface, we have to use the Rittinger's law in terms of Sauter diameter or volume surface mean diameter. So whatever value we are given for feed as well as product.

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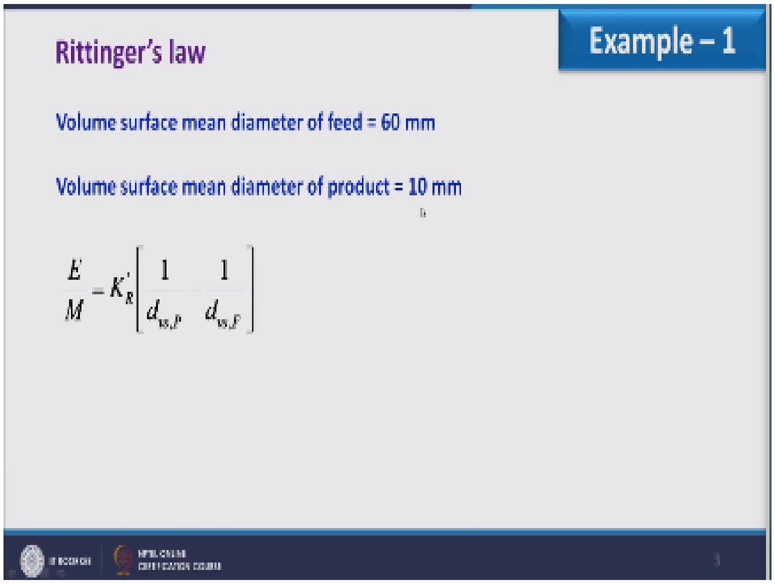

That we can assume as the volume surface, mean diameter. So for feed volume surface mean diameter is equal to 60 mm and volume surface mean diameter of product is 10 mm, so that we have assumed to be used in this expression.

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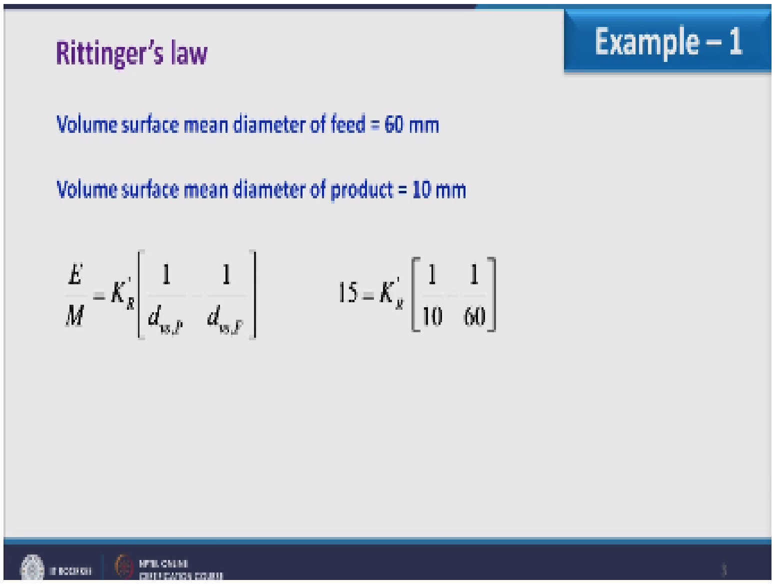

So once I use the value of d_{vsp} and d_{vsf} in this E/M I already know, so here I will write the value of E/M which is given as 15 K_R' that we have to compute, 1/10 that is the value of volume surface mean diameter of product, -1/60 60 is the value of volume surface mean diameter of feed. So considering all these value that is energy consumption, mean diameter of feed as well as product we can calculate the value of K_R' constant.

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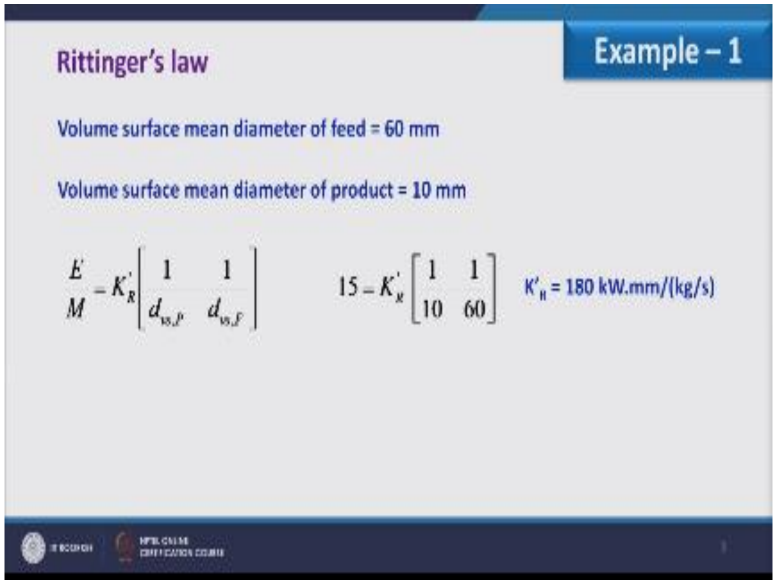

We can say revise Rittinger's constant and is equal to 180 kW mm/kg/sec. So this K_R' value we can use to calculate the power consumption using Rittinger's law when we have to crush the material from 80 mm size to 20 mm size which is the second part of the problem, here we can calculate E/M value.

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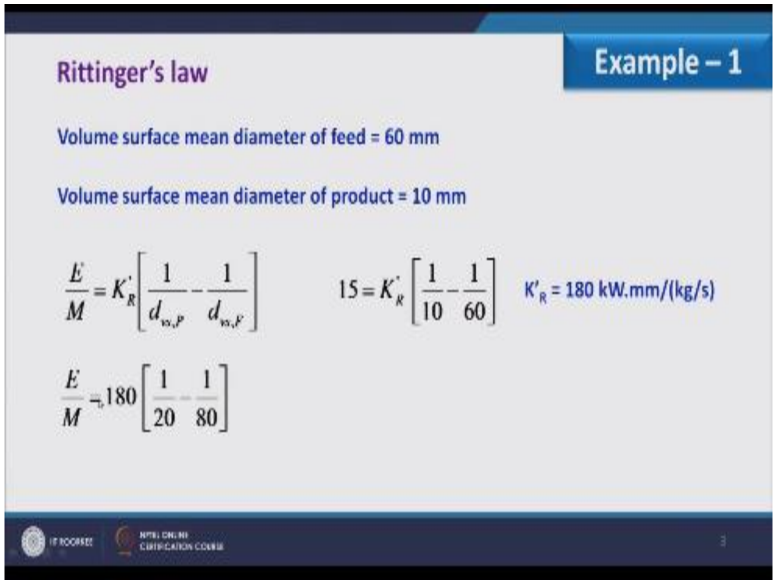

Which is equal to 180 the value of K_R' we can K_R' as it is over here because we are using the same material to be further crushed from 80 to 20, so here we will again assume that volume surface mean diameter of feed is 80mm and volume surface mean diameter of product is 20mm.

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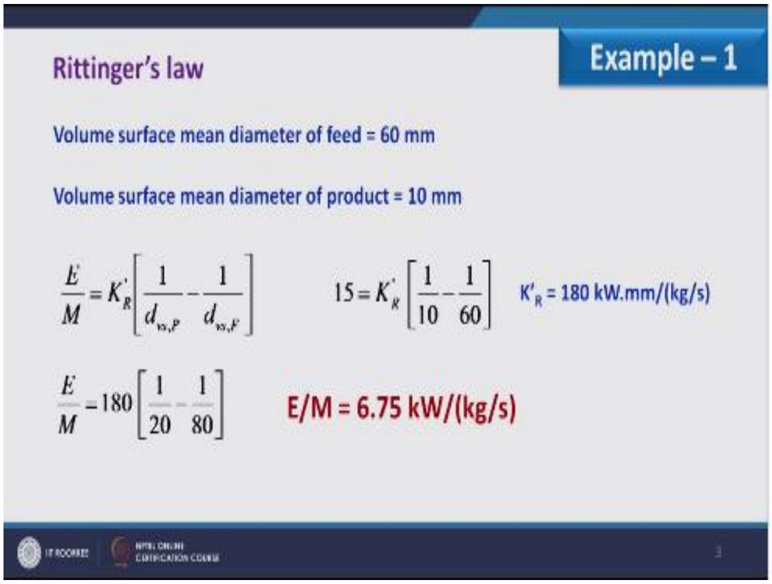

So considering the value of K_R' DVSP and DVSF we can calculate energy consumption per unit feed rate using Rittinger's law which comes out as 6.7 kW / (kg/s), so here you see we have solved a very simple example in which a feed size is given, product size is given and we have computed the energy consumption using Kick's law as well as Rittinger's law. Here Rittinger's law we have used slightly differently, instead of surface area we have used volume surface mean diameter of feed and product, so this a simple example how to calculate the energy consumption using Kick's as well as Rittinger's law.

Now here I have considered a complicated problem as example 2, now in this example what happens.

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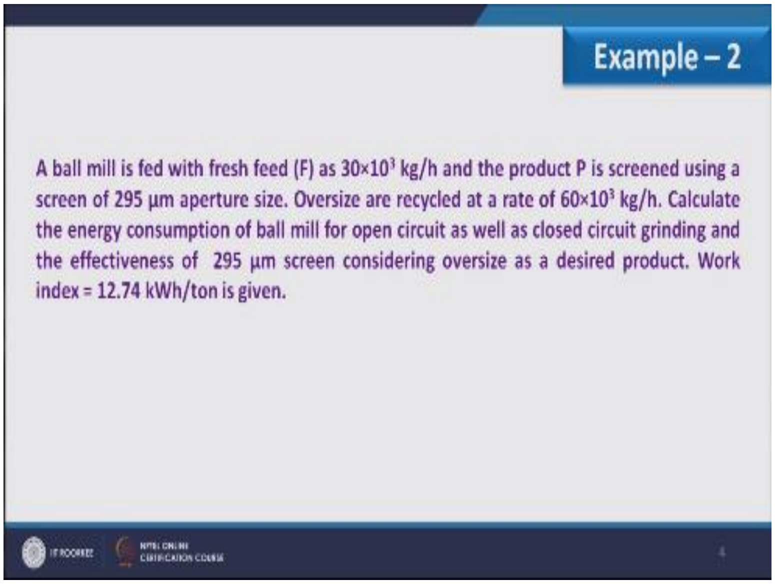

We have a ball mill and this ball mill is fed with fresh feed that is F as 30x 10^3 kg/ h or 30t/ h, so feed to the ball mill that we call fresh feed or we can call it maker feed also which is 30t/h and product P is a screen, using a screen of 295 μm aperture size, now where this F and P in ball mill that we can see from this.

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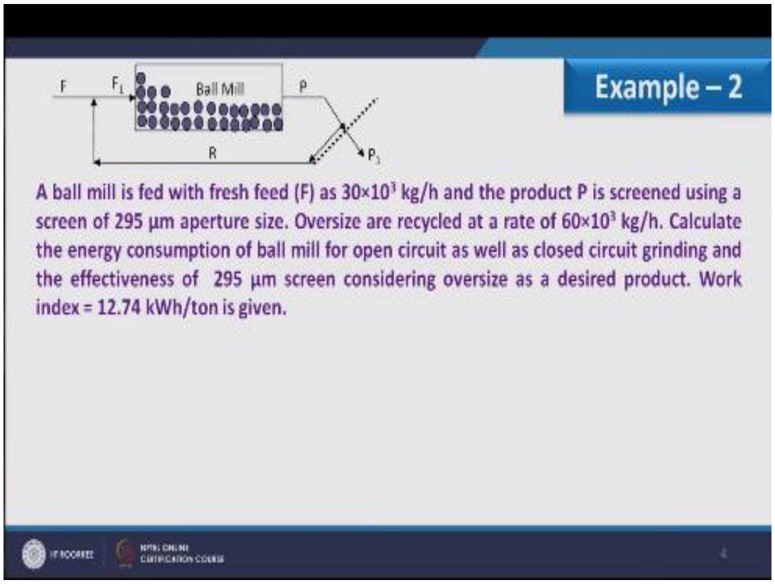

Figure now if you see this figure this the ball mill and in this ball mill F_1 feed is entering, now what is this F then? F is nothing but the maker feed to ball mill so as far as maker feed is concerned we have denoted this with F and the feed to ball mill is concerned that we have denoted with F_1. So product of ball mill that is P is coming from ball mill after crushing and this product is passed through a screen which is having aperture size of 295 µm, then this P is passed through this screen, some of the material is collected as undersize and this we have donated as P_1, the oversize of this screen is undesirable so that will be recycled back to the crusher.

So in this case F is the maker feed and P_1 is the final product R we have denoted as recycle, so the problem goes as oversize are recycled at a rate of 60 $x10^3$ kg/h so this R value is having the rate of 60 ton/ h, now what we have to calculate the energy consumption of ball mill for open circuit as well as closed circuit grinding and further we have to calculate the effectiveness of 295 µm screen considering oversize as the desired product.

For this problem work index is given to us that is 12.74 kWh/ ton, now as we know that work index is related with the Bond's law so we have to calculate energy consumption in this example suing Bond's law. Example 1 I have shown the computation using Kick's law as well as

Rittinger's law, here I have considered Bond's law to demonstrate how the energy consumption will be calculated using this.

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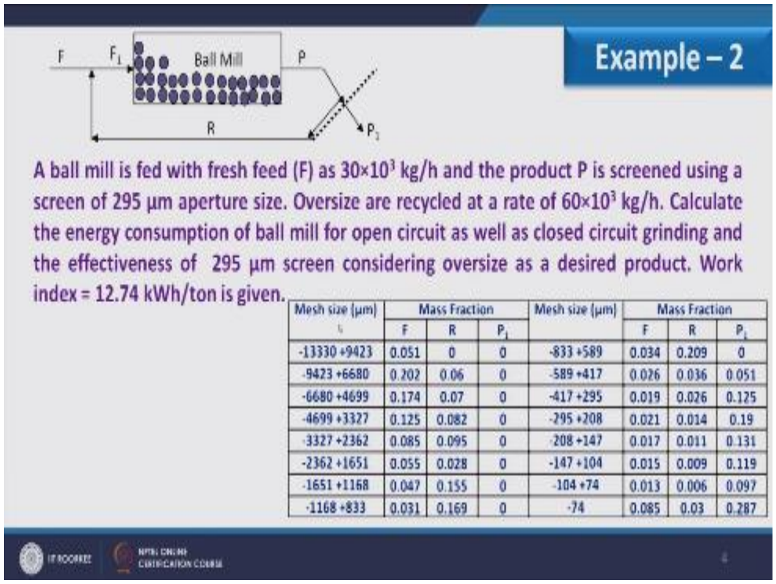

Mesh size (μm)	Mass Fraction			Mesh size (μm)	Mass Fraction		
	F	R	P_1		F	R	P_1
-13330 +9423	0.051	0	0	-833 +589	0.034	0.209	0
-9423 +6680	0.202	0.06	0	-589 +417	0.026	0.036	0.051
-6680 +4699	0.174	0.07	0	-417 +295	0.019	0.026	0.125
-4699 +3327	0.125	0.082	0	-295 +208	0.021	0.014	0.19
-3327 +2362	0.085	0.095	0	-208 +147	0.017	0.011	0.131
-2362 +1651	0.055	0.028	0	-147 +104	0.015	0.009	0.119
-1651 +1168	0.047	0.155	0	-104 +74	0.013	0.006	0.097
-1168 +833	0.031	0.169	0	-74	0.085	0.03	0.287

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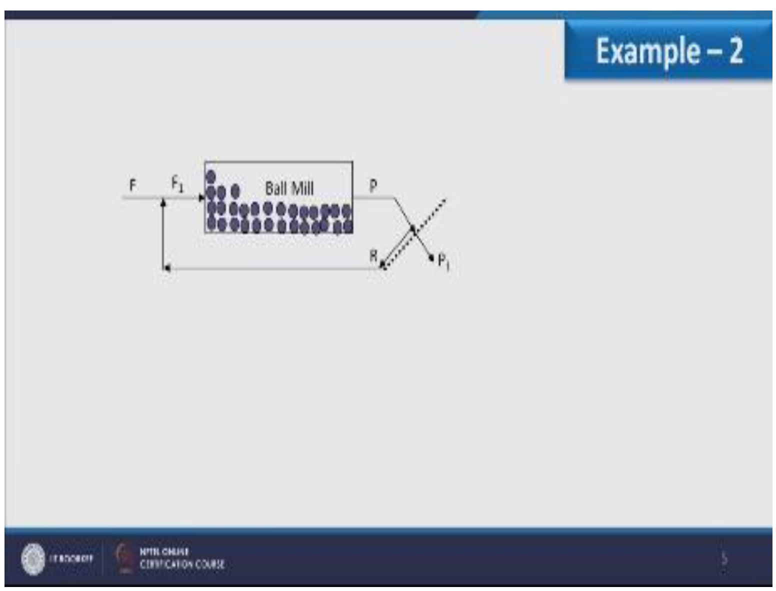

Denoted the closed circuit if you understand the 5th lecture of week 2 where we have discussed different mode of operation for size reduction, so the complete diagram shows the closed assembly of.

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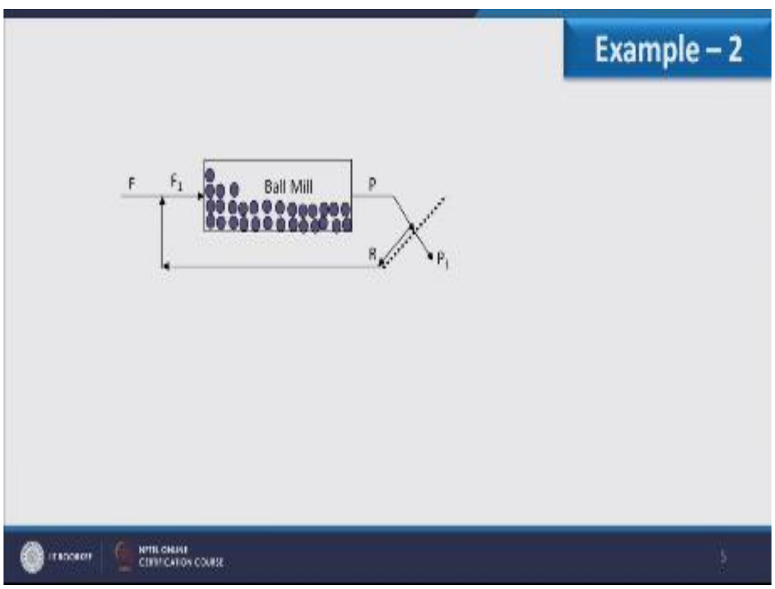

Crushing, now in this diagram what is the open cycle and what is the closed cycle or what is open circuit what is closed circuit? If you understand open circuit it says that material passed from one end or to the crusher and will leave from other end of the crusher so considering this if we understand.

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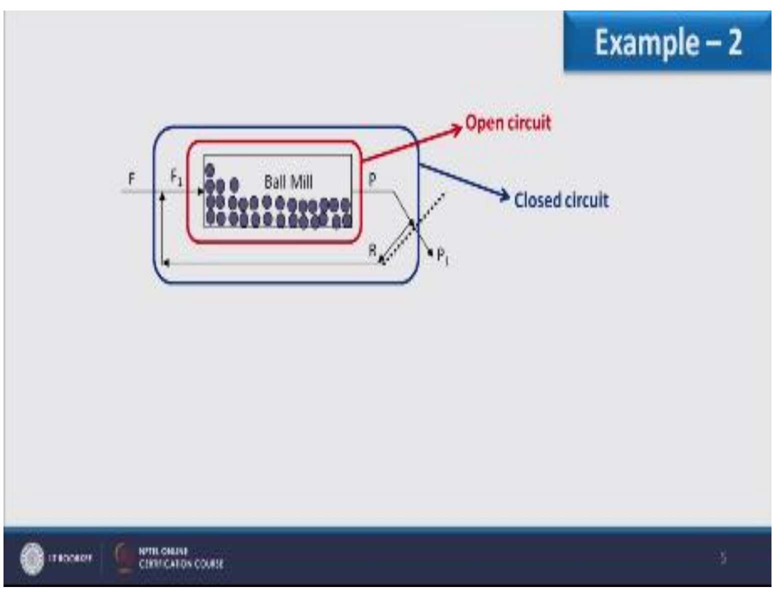

The ball mill and only and we enclose the ball mill where if I consider input and output to this enclosure F_1 would be the input and capital P would be the output, so as far as open circuit definition is concerned material which is passed into the crusher and material which is leaving from the crusher, so F_1 and P if I am considering it is the part of open circuit and if I consider the recycle part inside this then we can call this as a closed circuit because close circuit has some material which is undesirable which is continuously fed to the ball mill, so if I consider close circuit.

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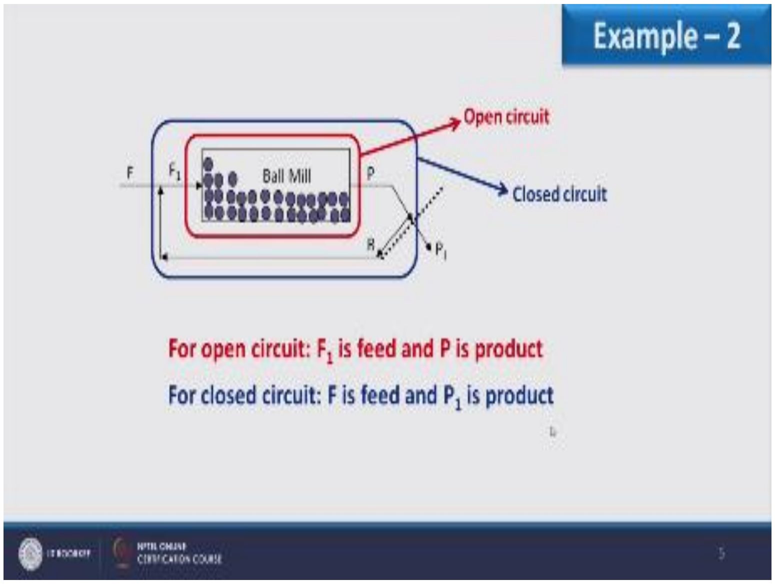

Then in it to the closed circuit is capital F and exit to the closed circuit is P_1, so if I have to calculate power consumption for open circuit I have to focus on F_1 and P where F_1 would be the feed and P would be the product, if I consider closed circuit then f is the feed and P_1 is the product so I hope you are understanding what is open circuit and closed circuit in a crusher problem. So here what we have to do, first of fall we have to complete the data for computation purpose, now what is left in the data table.

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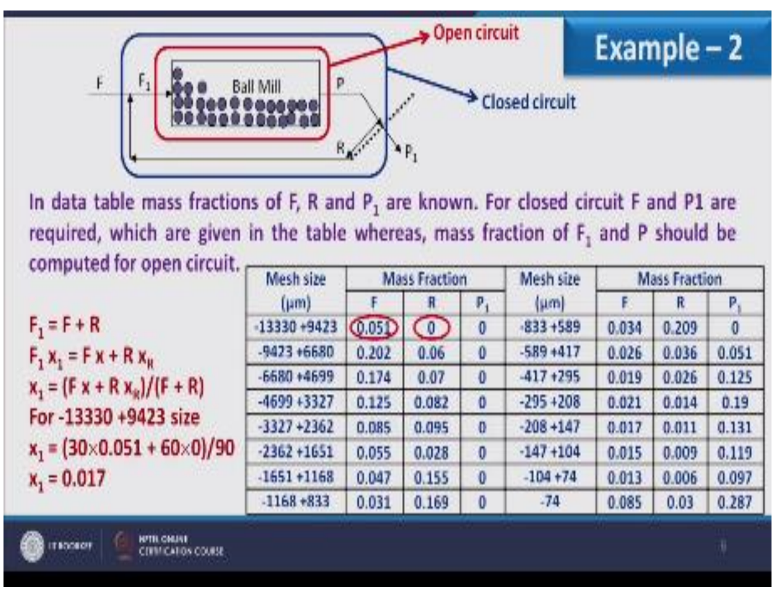

Mesh size (μm)	Mass Fraction F	Mass Fraction R	Mass Fraction P_1	Mesh size (μm)	Mass Fraction F	Mass Fraction R	Mass Fraction P_1
-13330 +9423	0.051	0	0	-833 +589	0.034	0.209	0
-9423 +6680	0.202	0.06	0	-589 +417	0.026	0.036	0.051
-6680 +4699	0.174	0.07	0	-417 +295	0.019	0.026	0.125
-4699 +3327	0.125	0.082	0	-295 +208	0.021	0.014	0.19
-3327 +2362	0.085	0.095	0	-208 +147	0.017	0.011	0.131
-2362 +1651	0.055	0.028	0	-147 +104	0.015	0.009	0.119
-1651 +1168	0.047	0.155	0	-104 +74	0.013	0.006	0.097
-1168 +833	0.031	0.169	0	-74	0.085	0.03	0.287

Which is given to us, in this data table mass fraction of F, R and P_1 are shown. For closed circuit if I consider this closed circuit F is used as feed and P1 is used as a product, so if you consider this table here I am having the fraction of F as well as P_1 so here you can see the fraction of F as well as P_1, so for closed cycle size distribution of feed as well as product both are given to us however if I consider the open circuit where feed is F_1 and product is capital P, so you can see in this table no data of F_1 as well as P is known to us.

And therefore we have to compute the size distribution of F_1 and P to calculate the power consumption of open cycle, so how I can calculate the size distribution of F_1 by making material as well as component balance? If you consider this F_1 that would be nothing but $\sum$ of F + R so here we have $F_1 = F + R$.

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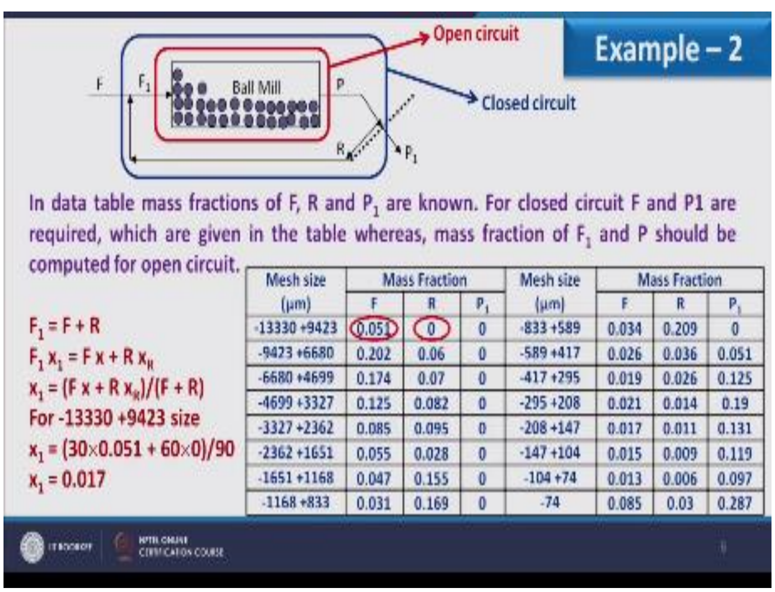

F is given as 30 tons and R is given as 60 ton per hour so this is the mass balance before entering to the ball mill and component balance is F_1, X_1 = FX + RX_R, and from here as we have to calculate the mass fraction for F_1 stream so we can calculate X_1 from this expression. X_1 would be (FX + RX_R/ F + R) divided by basically F_1 and that F_1 we have replaced with F and R because values of F and R are given to us.

So if I consider the mass fraction for this particular interval which is basically – 13.33mm + 9.423mm so for this size we can calculate X_1 as 30 x F that is 0.051 + 60 x 0/ 90, so using this expression for each size interval we can calculate value of X_1 so corresponding to first size that is – 13.33mm + 9.423mm the value of X_1 has come as 0.017. In similar line we can calculate the fraction for other sizes also and once I will calculate this we can represent.

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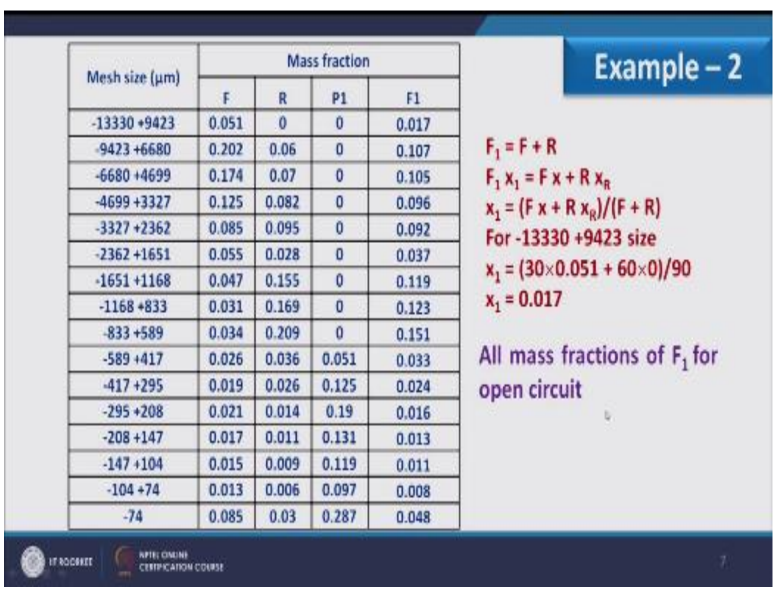

Mesh size (μm)	Mass fraction			
	F	R	P1	F1
-13330 +9423	0.051	0	0	0.017
-9423 +6680	0.202	0.06	0	0.107
-6680 +4699	0.174	0.07	0	0.105
-4699 +3327	0.125	0.082	0	0.096
-3327 +2362	0.085	0.095	0	0.092
-2362 +1651	0.055	0.028	0	0.037
-1651 +1168	0.047	0.155	0	0.119
-1168 +833	0.031	0.169	0	0.123
-833 +589	0.034	0.209	0	0.151
-589 +417	0.026	0.036	0.051	0.033
-417 +295	0.019	0.026	0.125	0.024
-295 +208	0.021	0.014	0.19	0.016
-208 +147	0.017	0.011	0.131	0.013
-147 +104	0.015	0.009	0.119	0.011
-104 +74	0.013	0.006	0.097	0.008
-74	0.085	0.03	0.287	0.048

All F1 value in terms of X_1 so if you see initially we have computed X1 as 0.017 that I have put over here and further if I want to calculate this so this into 30 + this into 60/ 90, so following the same expression we can calculate mass fraction of F_1 which is the feed to open circuit, so in this table all mass fractions of F1 for open circuit are shown. In the similar line I can calculate data for P because F1 we have calculated now I have to calculate data for P.

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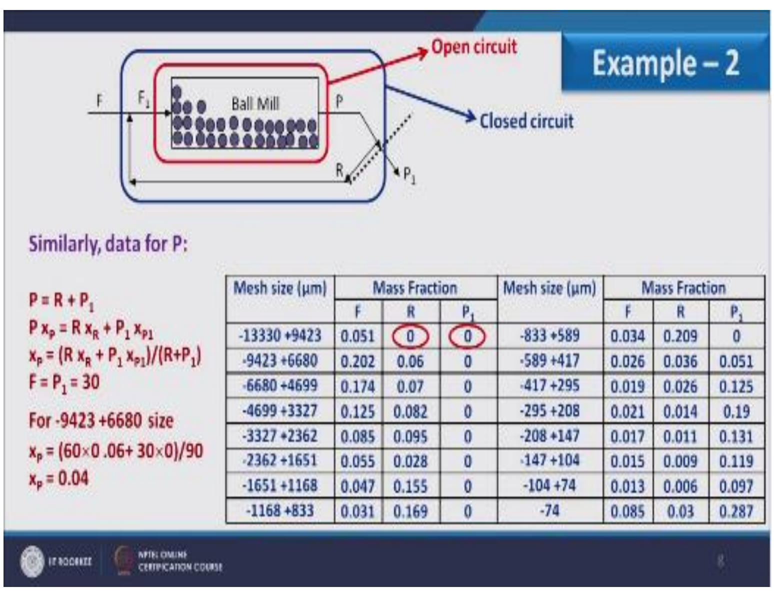

Now if you make the balance over P what it will give P = R+P1, so that is the balance P=R+P1, if we make the component balance P x_P=R x_R + $P_1 x_{P1}$. So we have to calculate x_P that is the distribution of this with respect to each size so x_P would be equal to (R x_R+P_1 xP_1)/(R+P_1). Now how we can calculate P_1 value, because R I know as 60 tons per hour.

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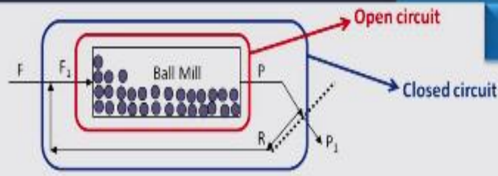

Similarly, data for P:

$P = R + P_1$

$P\,x_P = R\,x_R + P_1\,x_{P1}$

$x_P = (R\,x_R + P_1\,x_{P1})/(R+P_1)$

$F = P_1 = 30$

For -9423 +6680 size

$x_P = (60\times0.06 + 30\times0)/90$

$x_P = 0.04$

Mesh size (μm)	Mass Fraction			Mesh size (μm)	Mass Fraction		
	F	R	P_1		F	R	P_1
-13330 +9423	0.051	0	0	-833 +589	0.034	0.209	0
-9423 +6680	0.202	0.06	0	-589 +417	0.026	0.036	0.051
-6680 +4699	0.174	0.07	0	-417 +295	0.019	0.026	0.125
-4699 +3327	0.125	0.082	0	-295 +208	0.021	0.014	0.19
-3327 +2362	0.085	0.095	0	-208 +147	0.017	0.011	0.131
-2362 +1651	0.055	0.028	0	-147 +104	0.015	0.009	0.119
-1651 +1168	0.047	0.155	0	-104 +74	0.013	0.006	0.097
-1168 +833	0.031	0.169	0	-74	0.085	0.03	0.287

But how I can calculate P_1, if you consider this closed circuit what is the inlet to this is F and what is the outlet of this is P_1 so if we make the balance over this envelope then F would be equal to P_1. As in the problem F is given as 30 tons per hour so the same value we can use for P_1, so $F=P_1$ for 30 ton per hour. Now if I consider for this particular size here both R and P_1 are 0 so no value we can obtain for P also, further if I consider second size that is -9423 +6680 for this we can calculate (60x0.06+30x0)/90, so x_P over here we can get 0.04.

So following this method we can calculate all fractions of P corresponding to different sizes, so in this table all mass fraction of P for open circuit are shown.

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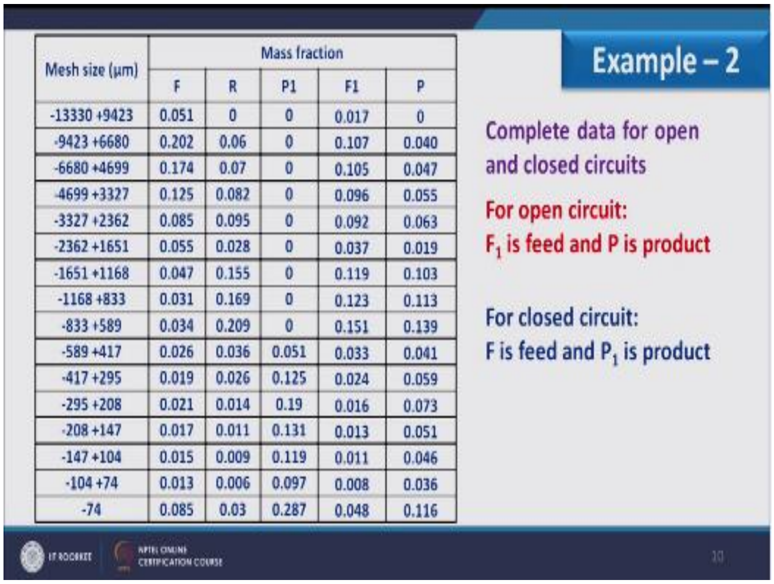

Mesh size (μm)	Mass fraction				
	F	R	P1	F1	P
-13330 +9423	0.051	0	0	0.017	0
-9423 +6680	0.202	0.06	0	0.107	0.040
-6680 +4699	0.174	0.07	0	0.105	0.047
-4699 +3327	0.125	0.082	0	0.096	0.055
-3327 +2362	0.085	0.095	0	0.092	0.063
-2362 +1651	0.055	0.028	0	0.037	0.019
-1651 +1168	0.047	0.155	0	0.119	0.103
-1168 +833	0.031	0.169	0	0.123	0.113
-833 +589	0.034	0.209	0	0.151	0.139
-589 +417	0.026	0.036	0.051	0.033	0.041
-417 +295	0.019	0.026	0.125	0.024	0.059
-295 +208	0.021	0.014	0.19	0.016	0.073
-208 +147	0.017	0.011	0.131	0.013	0.051
-147 +104	0.015	0.009	0.119	0.011	0.046
-104 +74	0.013	0.006	0.097	0.008	0.036
-74	0.085	0.03	0.287	0.048	0.116

So this is the complete data for open as well as closed circuit. In open circuit what are the parameter, F_1 we should know and P we will know, so for open circuit F_1 and P will be utilized to calculate power consumption, however for closed circuit F and P1 is utilized to calculate power consumption, so this is the complete data for computation of power consumption using open as well as closed circuit. Let us start the computation for open circuit where we have to consider F_1 is feed and P as product, for closed cycle F is feed and P_1 is product.

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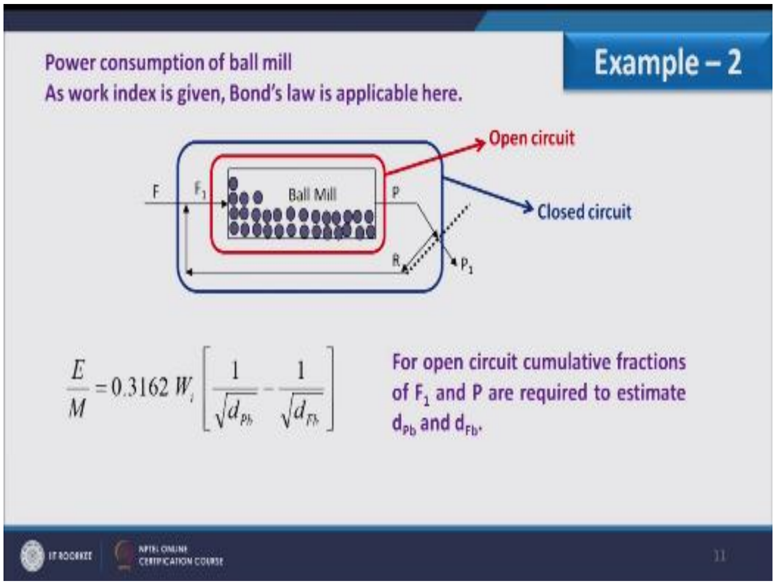

So here we have to start calculation for open circuit considering F_1 as well as P and this expression we have to use to calculate power consumption this is nothing but the Bond's law. Why we are using Bond's law, because in the beginning we are given the work index of the material, so which automatically comes for Bond's law. So in this expression you see what is d_{Pb} and d_{Fb}, d_{Pb} is corresponding to the size where 80% of product is passed through and d_{Fb} is the size where 80% of feed is passed through a particular screen. So if I consider the open cycle.

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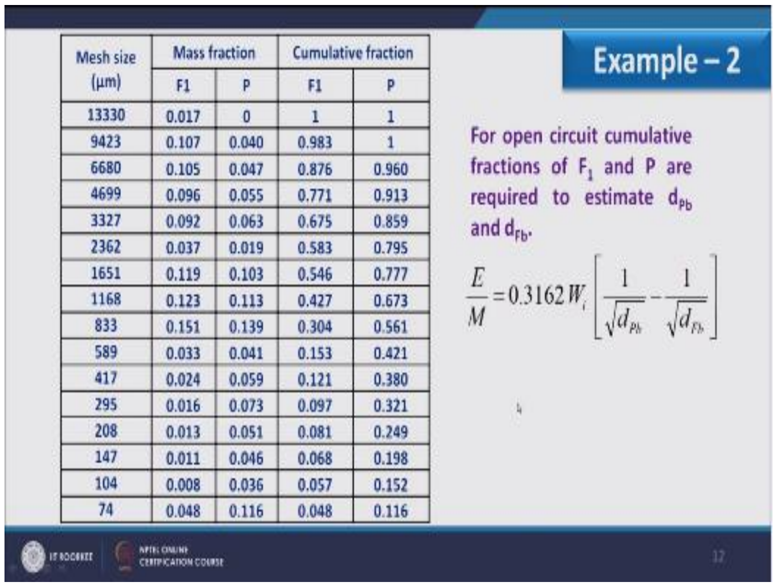

Mesh size (µm)	Mass fraction		Cumulative fraction	
	F1	P	F1	P
13330	0.017	0	1	1
9423	0.107	0.040	0.983	1
6680	0.105	0.047	0.876	0.960
4699	0.096	0.055	0.771	0.913
3327	0.092	0.063	0.675	0.859
2362	0.037	0.019	0.583	0.795
1651	0.119	0.103	0.546	0.777
1168	0.123	0.113	0.427	0.673
833	0.151	0.139	0.304	0.561
589	0.033	0.041	0.153	0.421
417	0.024	0.059	0.121	0.380
295	0.016	0.073	0.097	0.321
208	0.013	0.051	0.081	0.249
147	0.011	0.046	0.068	0.198
104	0.008	0.036	0.057	0.152
74	0.048	0.116	0.048	0.116

There F_1 and P are required to estimate d_{Pb} and d_{Fb} so what we have done over here we have done the cumulative fraction of F_1 as well as P. This is the individual fraction and here I have the cumulative fraction and you understand that if we do the cumulative from bottom we have to represent the screen or mesh corresponding to negative signs. So here we have cumulative of F_1 and here we have cumulative of P, now this two value we will use for computation of power consumption, if you understand this graph.

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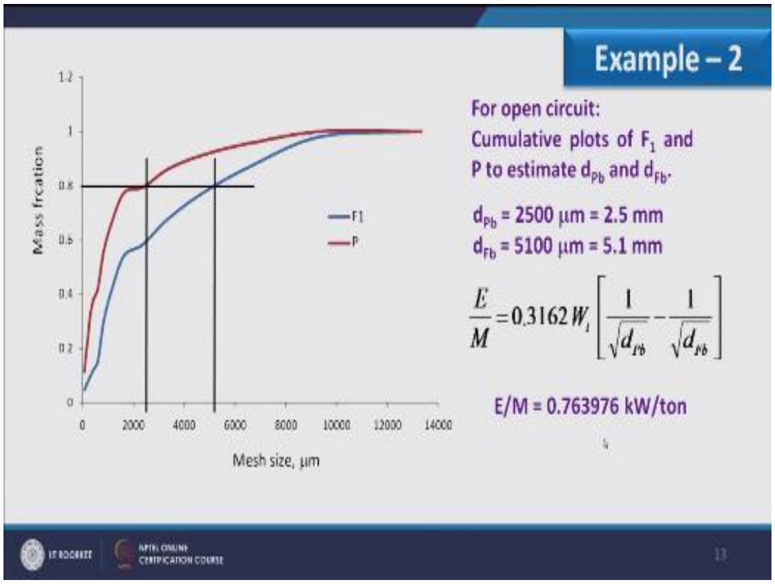

This is nothing but the cumulative plot of F1 as well as P. Now d_{Pb} and d_{Fb} I have to compute according to the 80%, so I will draw a line of 80% and then draw the line where I am having the cut at F1 as well as on P. So d_{Pb} basically we can see from this graph is this value which is 2500 μm and d_{Fb} from this graph we can take as 5100 μm, which we have to show in terms of mm so 2.5mm and 5.1mm because that is the requirement to be used in Bond's law. So E/M is given here which is 0.3162 work index and all these value are known to us, when we put the value over here we can calculate E/M.

Now if you consider this open circuit here we have material in total as 90 ton per hour, because 30 ton from makeup and 60 ton from recycle, so this value.

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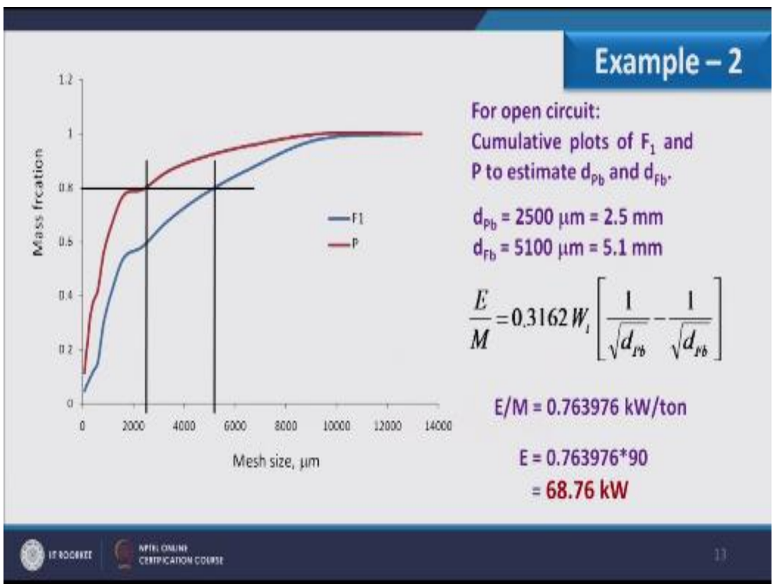

We have multiplied with 90 so 68.76 kW would be the energy consumption for open cycle. In the similar line for closed cycle we will use F and P_1.

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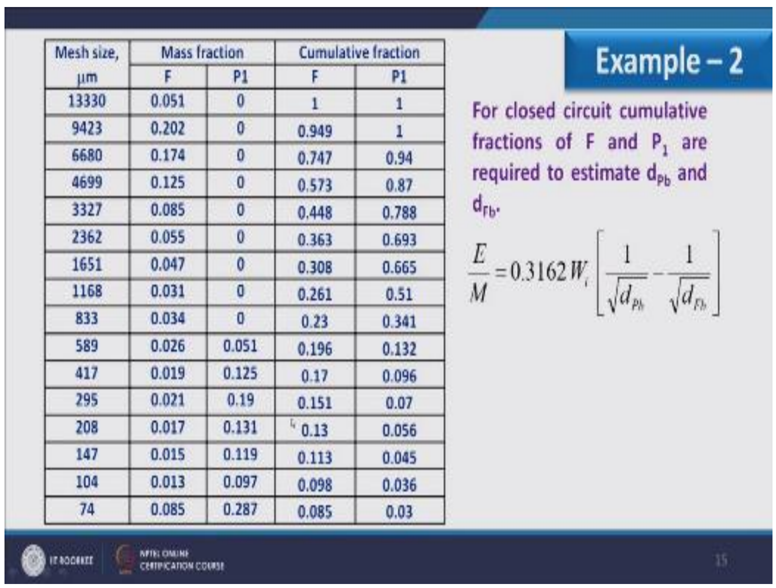

Mesh size, µm	Mass fraction		Cumulative fraction	
	F	P1	F	P1
13330	0.051	0	1	1
9423	0.202	0	0.949	1
6680	0.174	0	0.747	0.94
4699	0.125	0	0.573	0.87
3327	0.085	0	0.448	0.788
2362	0.055	0	0.363	0.693
1651	0.047	0	0.308	0.665
1168	0.031	0	0.261	0.51
833	0.034	0	0.23	0.341
589	0.026	0.051	0.196	0.132
417	0.019	0.125	0.17	0.096
295	0.021	0.19	0.151	0.07
208	0.017	0.131	0.13	0.056
147	0.015	0.119	0.113	0.045
104	0.013	0.097	0.098	0.036
74	0.085	0.287	0.085	0.03

And here we will make the cumulative for f as well as p1 to know were 80% mass will lie. We make the plot over here for f as well is p_1, this is the cumulative plot of p1, this is the cumulative plot of f correspond to 80% we can draw the line and then we can calculate d_{pb} and d_{fb} as 3.5 mm and 7.15 mm. Considering this value along with work index we can calculate the power consumption, we can calculate energy consumption per unit mass. If I consider closed cycle

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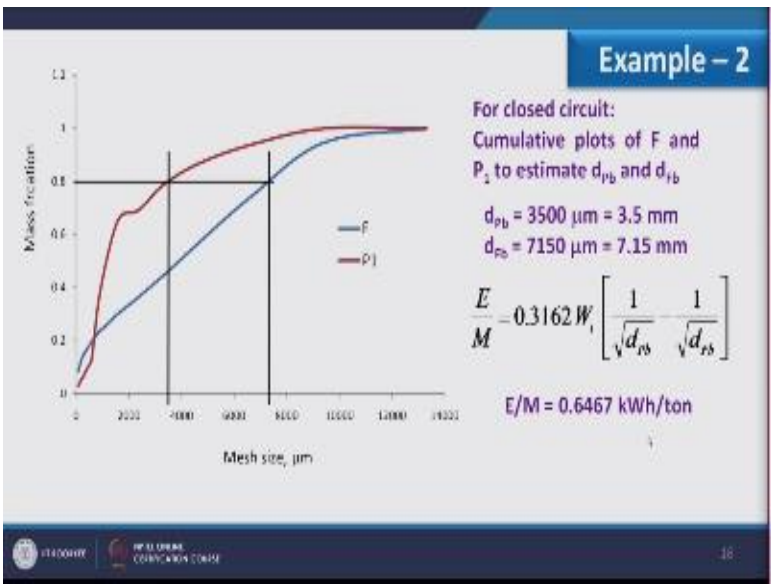

The mass which is entering to this is 30 ton per hour so that m we can take as 31 so this is, this we can multiply with 0.6467 total 19.4 kW is the power consumption for this cycle which is closed. Further we can consider.

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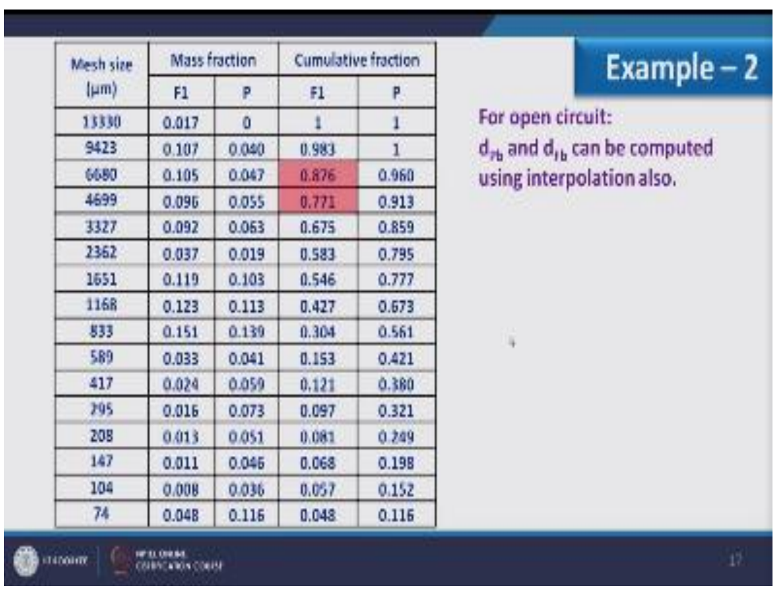

Mesh size (μm)	Mass fraction		Cumulative fraction	
	F1	P	F1	P
13330	0.017	0	1	1
9423	0.107	0.040	0.983	1
6680	0.105	0.047	0.876	0.960
4699	0.096	0.055	0.771	0.913
3327	0.092	0.063	0.675	0.859
2362	0.037	0.019	0.583	0.795
1651	0.119	0.103	0.546	0.777
1168	0.123	0.113	0.427	0.673
833	0.151	0.139	0.304	0.561
589	0.033	0.041	0.153	0.421
417	0.024	0.059	0.121	0.380
295	0.016	0.073	0.097	0.321
208	0.013	0.051	0.081	0.249
147	0.011	0.046	0.068	0.198
104	0.008	0.036	0.057	0.152
74	0.048	0.116	0.048	0.116

Open circuit and we can calculate power consumption using interpolation, here for open circuit f_1 and p will be considered and you see the 80 % were it will lie from this table we can calculate from interpolation also. How I can use the interpolation over here because between 2 point straight line will lie so I can definitely use interpolation, so 80 % will lie over here so d_f would be lie in between these two however as well as product line is concerned 80 % will lie in between these two so d_p will lie in between these two, so using interpolation we can calculate and d_{pb} and finding as 2.437 which was 2. 5 in the graphical representation and d_{fb} value 5.246 mm we can find from the interpolation. Using these two values along with work index we can calculate power consumption it will be multiplied with 90 ton so 73.95 kW is the power consumption

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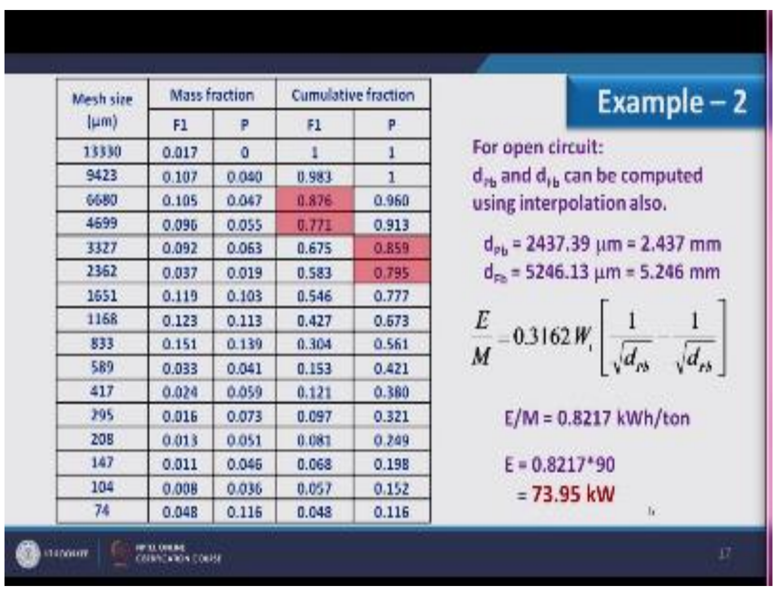

For open cycle. And similarly I can calculate for closed cycle using interpolation so if I consider feed to close cycle f I have to consider and 80 % will lie in between these two, similarly in p_1 80% will lie in between these two so using interpolation I can calculate d_{pb} and f_{db} and further using work index as well as these values I can calculate power consumption, it would be multiplied by 30 and final power consumption for closed cycle is 19.92 kW.

So this is the power consumption for closed cycle as well as open cycle, now finally we have to calculate the effectiveness of

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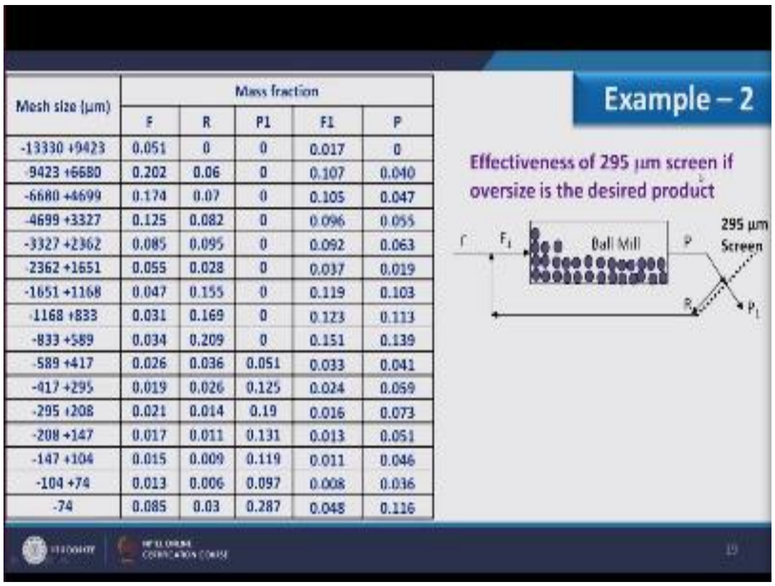

Mesh size (μm)	Mass fraction				
	F	R	P1	F1	P
-13330 +9423	0.051	0	0	0.017	0
-9423 +6680	0.202	0.06	0	0.107	0.040
-6680 +4699	0.174	0.07	0	0.105	0.047
-4699 +3327	0.125	0.082	0	0.096	0.055
-3327 +2362	0.085	0.095	0	0.092	0.063
-2362 +1651	0.055	0.028	0	0.037	0.019
-1651 +1168	0.047	0.155	0	0.119	0.103
-1168 +833	0.031	0.169	0	0.123	0.113
-833 +589	0.034	0.209	0	0.151	0.139
-589 +417	0.026	0.036	0.051	0.033	0.041
-417 +295	0.019	0.026	0.125	0.024	0.059
-295 +208	0.021	0.014	0.19	0.016	0.073
-208 +147	0.017	0.011	0.131	0.013	0.051
-147 +104	0.015	0.009	0.119	0.011	0.046
-104 +74	0.013	0.006	0.097	0.008	0.036
-74	0.085	0.03	0.287	0.048	0.116

295 mm screen, if I have to calculate effectiveness to this what is the feed to this is p, oversize is R and P_1 is the undersize. So what is the desired product over here is the oversize, so to calculate effectiveness of this screen we have to consider these three columns which are R, $p_1$as well as p, and you understand how we calculate the effectiveness we have to calculate y_a, y_b and y_c, y_a is the desire material in feed so in this case all these fraction combinely will give the y_a, y_b is the r value up to here and y_c is basically the p_1 value up to 295 screen. So using this y_a y_b and y_c when we put in this particular expression we can get the effectiveness which is coming out as 78.09%.

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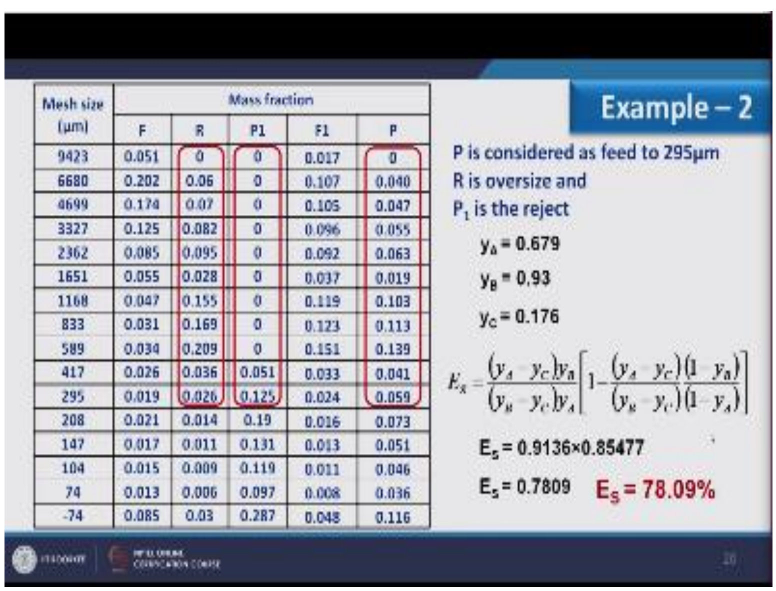

So here I am completing example 2 and as far as this part of lecture is concerned here I am stopping, I will consider example three, four and five in next part of lecture two, that is all for now, thank you.

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