METALLURGICAL AND ELECTRONIC WASTE RECYCLING

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Week-1

Lecture-4

Greetings, so I welcome you to the fourth lecture of this course and today we are going to discuss on importance of unit operations on material recovery. So, in the previous lectures we have already gone through some of the basic introduction that is necessary to understand what metallurgical and electronic waste recycling. But as we go along, we will now develop some important concepts that are essential to understand how these waste streams are recycled. In the previous lectures, we have also seen the importance of unit operations.

So, for instance when we look at a given waste stream what is our first reaction? When we think of the first reaction the first thing that should come into mind is can we separate out these waste streams into different categories based on their valuable content. So, even before when we tried to jump here we'd like to go and discuss why it is necessary why is it necessary to put up and to calculate the economic values so suppose that we have an e-waste stream that can comprise of mobile phones discarded mobile phones of course PC's and in this we can have the WPCB's, waste printed circuit boards and of course this can come from mobile phones as well so we can have discarded electronics like we can have washing machines, lamps and so on so forth.

What is the first thing that we do? We will have to identify valuable resources. And then we can just go on and think of the unit operations that will be essential to tap onto these valuable resources. So, when we think of unit operations, we have put up some numbers, some value okay, a given stream will have such and such valuable resources. Now, we are trying to grab onto those resources.

The first thing that we should be taking care of is bringing down the particle size. It is possible by crushing, grinding and of course, the size reduction due to these processes, size reduction and separation, separation based on these operations. crushing, grinding and size reduction, sieving, fragmenting the given feed into various size fraction, understanding the size distribution that is obtained after the crushing and grinding circuit is followed. After the circuit is completed, we get a wide spectrum of particle sizes. Which particle size fraction has what type of valuable material that people can do the further characterization and then decide okay coarse particles have such and such valuable materials, finer fraction have such and such materials. So, of course, this comes only after the comminution step. So, one has to think of crushing, grinding, size separation, size distribution, attaining the size distribution and then the rest of the process can be developed. A generalized way of estimating how much energy would be required for size reduction can be given by three important laws.

The first one is the Kick law. The Kick law, according to the Kick law, and of course, all of these laws are basically governed by a general law which is stated here.

$$dE/dL = KL^n$$

where dE is the energy required for particle size reduction, dL is the change in the dimension, particle size dimension and K could be the constant, n again is another constant. So, when we think of various laws, the Kick law, the Rittinger law and the Bond law will have variations of K and n. So, for instance, when we look at the Kick law, dE on dL is again the Kick law constant (K_K).

$$\mathbf{dE/dL = K_k f_c L^{-1}}$$

This is the material constant that is involved for the specific material and we will see that the power here is minus 1. So, when we integrate it, we will reach here.

$$\mathbf{E = K_K f_c ln(L_1/L2)}$$

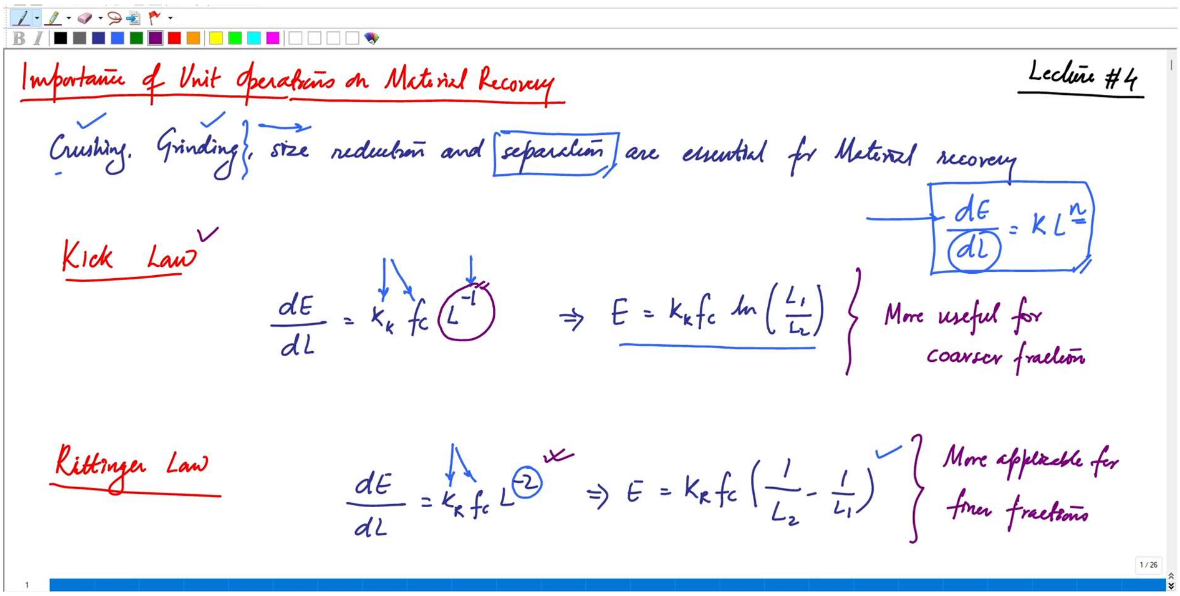
When we look at the Rittinger law just following on to the same principle dE on dL gives you K_R, again this is the Rittinger law constant, the material constant, and this time the power is minus 2.

$$\mathbf{dE/dL = K_R f_c L^{-2}}$$

So, we will have a relationship like this K_R, fc 1 upon L_2 minus 1 upon L_1.

$$E = K_r \cdot f_c \cdot \left(\frac{1}{L_2} - \frac{1}{L_1}\right)$$

(Ref. 6:36)



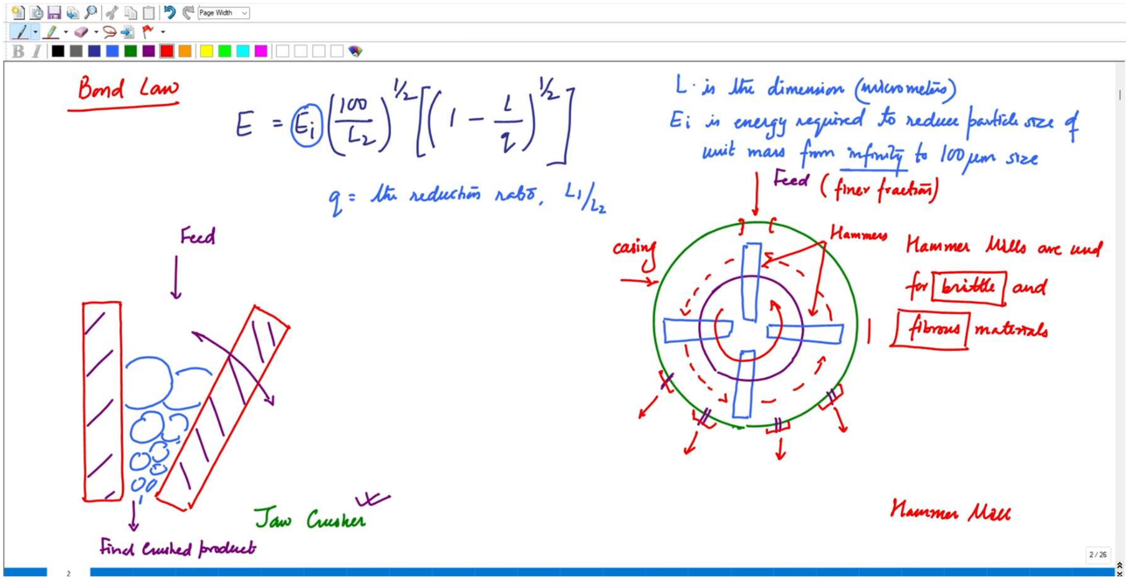
And the final one is the Bond law where E and we will see that this time n is basically minus 1.5. So, it and it and of course, it is being rearranged.

$$E = E_i \left(\frac{100}{L_2}\right)^{1/2} \left[\left(1 - \frac{1}{q}\right)^{1/2}\right]$$

So, we will now try to understand what are the terms in the Bond law, we will see that L is the dimension, the Ei term that is constant over here, Ei is the energy required to reduce particle size of unit mass from infinity to 100 micrometers and by infinity we mean very large particle size. So, it is we are trying to bring down the particle size to 100 micrometer and that is the energy required and of course, this length is in micrometers. L right now is being defined in micrometers.

Similarly, there is a term Q which is the reduction ratio given by L_1 on L_2. What is interesting in all of these three laws is that they help us in understanding what type of law would be used for what type of particles because it so happens that a single law is not able to describe what type of energy is required to bring down the particle size of a given feed material. So, for instance it has been observed that Kick law is more applicable, more useful for coarser fraction.

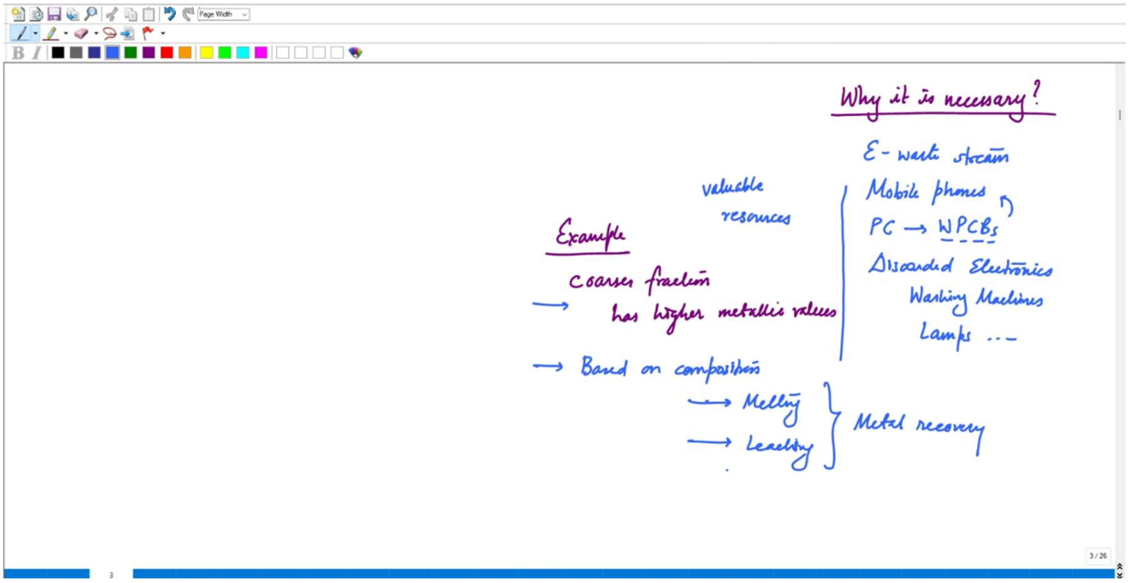
(Ref. 7:00)



Whereas the Rittinger law is more applicable for finer particles. finer fraction, finer particles. It also should be kept in mind that when we look at the Kick law, we will see that the power is minus 1, whereas for a Rittinger law, it is minus 2. Incidentally, the Kick law focuses that, it emphasizes that the energy required is proportional to the change in dimension the particle size dimension whereas the Rittinger law focuses that it emphasizes that the energy required is basically proportional to the generation of new surface area.

So, the power of n changes now it has been observed since people have tried to collate their experimental data with these laws, they found that the Kick law fits better for coarser particles and the Rittinger law fits better for finer fractions and the Bond law is somewhere in between. So, all three laws have their different segments where these can be applied. So, what happens when we are crushing and grinding the particles and bringing down the particle size? It is to be understood that these finer fractions or coarser fractions would be used for various intended applications.

So, for instance one would like to go ahead and characterize these fractions and suppose that they identify that coarser fraction has higher metallic content metallic values and of course this is an example. So, the first thing that would obviously come to our mind is that let us try and tap these metallic values. Based on composition, we could think of melting or leaching these coarser fractions and this would lead to metal recovery. Now, this is just an example. **(Ref. 13:00)**



So, for instance if we have coarser fractions we would like to directly go ahead and use these coarser fractions may be agglomerated and then just charge it into the furnace for melting and then recover the molten metal and cast it into various shapes. So, that is again one method of recovery while the other could be a more route that is directed towards hydrometallurgy where we could design a leaching setup, recovering metals into the aqua solutions and then trying to recover various metallic values from these leach liquor. So, this is how one can device, one can develop a progressive and economical recycling route so what it always begins at the first step understanding the raw material trying to see what is its worth how to recover it from the very first step.

So, comminution which is basically crushing grinding sieving understanding the various particle size distribution the initial characterization done All of these steps are very crucial. Now, when we think of understanding the communication scale, communication processes that we have been discussing, the first few key tools that are essential for developing a good recycling route is to understand the key equipment. These key equipment are the crushers and grinders.

So, the example of that is described here. We have the jaw crusher and here we have a hammer mill. The jaw crusher and the hammer mill so when we think of the jaw crusher we see that this is where we feed and in this case here we feed our material we see that one is stationary so one side of the jaw crusher is stationary the other one is So, when we see that the when this moving jaw crushes when it comes closer it crushes the particles and gradually what we get is the final crushed product. And based upon what is the dimension that we want, we can adjust the bites.

Similarly, we have the roll crushers and other types of gyratory crushers. These types of crushers are used to bring down particle size based on the availability of crusher and based on the type of material that we are trying to crush, we can select our crusher. Most commonly used is a jaw crusher. So, supposing that we are trying to grind. So, after crushing we have got a finer fraction and now we wish to grind.

So, for grinding operations there are various types of mills. One can think of ball mills or hammer mills or plate mills. So, a hammer mill is being described here wherein we are trying to understand how finer fractions can be made more finer. We are trying to reduce the particle size even further because when we are reducing the particle size increasing the specific surface area we are basically creating more surface that is available for reaction more surface available for reaction so suppose that this feed which is already finer fraction We wish to have even finer fraction that is reducing the sub particle size even to let us say 100 micrometers or even lesser 200 micrometers or even lesser.

So, that type of operation can be done using various types of mills and hammer mill, ball mills, these mills are generally used to reduce the particle size. The choice of a good grinding mill would basically depend on what is the type of the raw material. Hammer mills are basically used for brittle and fibrous materials. So, fortunately when we think of hammer mills, these can tackle, these can handle brittle as well as fibrous materials.

So, how does it really operate? Supposing that we are charging our feed from this end and these are basically the outer casing, this is casing and these are the hammers and these hammers tend to rotate. So, suppose that this hammer mill is operational, it is operating right now and the hammers are rotating. So, of course, these are the and we feed our raw material. What happens is it will get milled between the hammer and the casing.

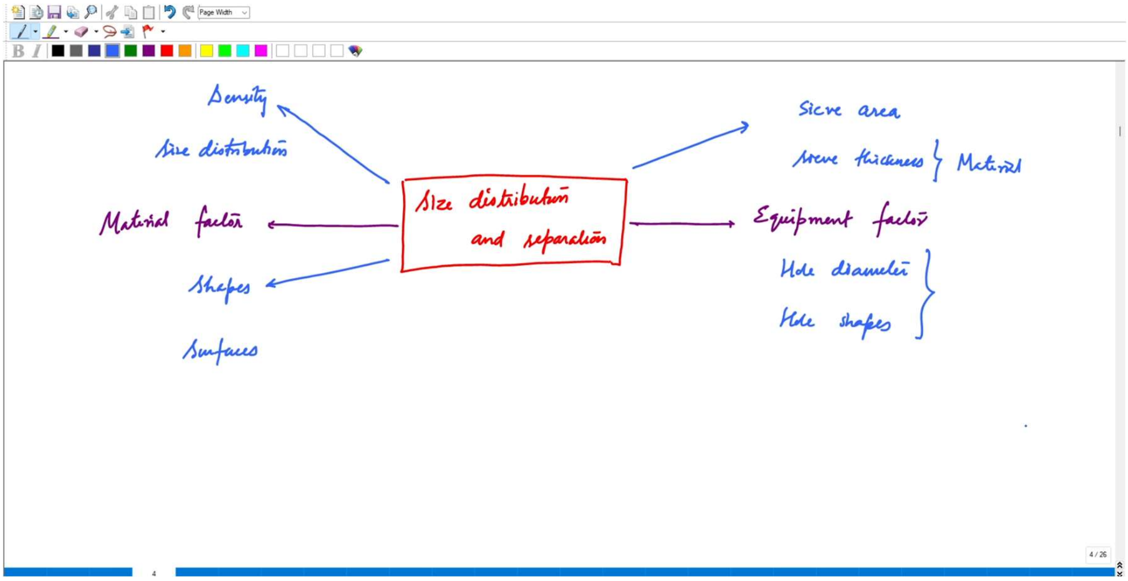
And gradually it starts to reduce in its particle size. So, the particle size are now gradually going to go down because it is getting crushed between the mill, between the hammer mills, the casing of the hammer mill and the hammer that are basically rotating at high speeds. So, and here we have small sieves. which basically allow only a small fraction to pass through it. So, the sieves are arranged in such a way that a given particle size which is lesser than that of the sieve will get discharged and the rest will continue to get reduced.

The rest of the particles will continue to get milled so that we get a fine fraction of particles. Now, one has to understand what exactly do we get after our commutation process. So, we get a coarser fraction which can be characterized.

We get a final fraction and then we characterize it one more time and supposing that we want to grind it further, then we would go ahead for various milling operations. But what happens to all of these fractions? One has to go for size distribution study. Size distribution and separation. So, let us now try and describe what exactly are we looking at when we think of size distribution and separation.

So, we have seen that we are through with the combination process. Now, what are the factors that really govern the size distribution? Density of a given material. Again, since the materials are different that are crushed or ground so there so depending on their densities we can have different types of size distribution. Similarly we'll have shapes shapes and surfaces so it is very difficult to predict the shape and surface of a given final feed product one has to study and then they will be able to comment on what type of surface is generated after the given comminution operation. One speculation here can be made that suppose that a given material is ductile. The chances of such material to become flattened is relatively higher when these are subjected to milling operations. Similarly, when we think of equipment factor, we will have sieve area.

What are the sieve? This basically is dependent upon what type of sieves we are using. What is the sieve area? The sieve thickness, this depends upon what type of material was used. Similarly, hole diameter and hole shapes again these are sieve characteristics what type of diameter the sieve had and what type of shapes these holes had through which the sieving operation was carried out. **(Ref. 25:41)**



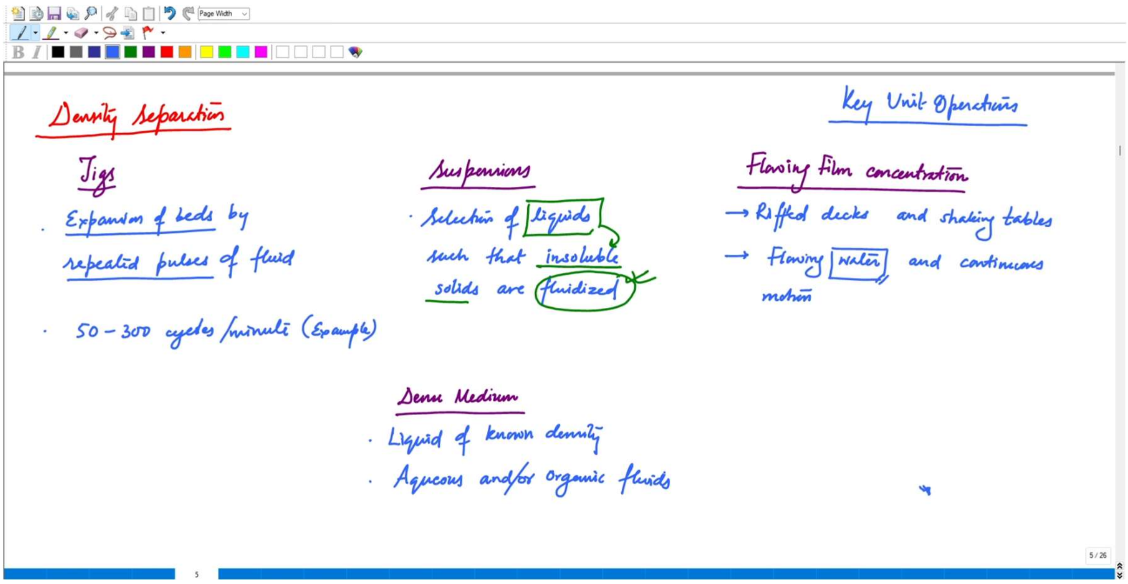
So, based on these we have different size particles and various separation size separation can be achieved using these parameters and these various sieves stacked one over other so of course the coarser sieve will be stacked on the top and then the finer and then the finest and we'll get a various particle size distribution. The other key unit operations that we had discussed previously involved not just crushing grinding but also on the basis of let us say media separation, heavy media separation or we can also think of magnetic separation. Based on these characteristics, one can think of applying the unit operations and achieving initial material separation.

So, we can think of density. We have jigs, suspensions, flowing film concentration and dense medium. All coming under the density separation segment of material treatment. Material pretreatment all again done under the segment of unit operations. When we think of jigs, the expansion of beds by repeated pulses, repeated pulses of fluid. So, we are thinking of expansion of beds by repeated pulses of fluid.

So, of course, we will have a fluid and then we will have our material and we will have repeated pulsing of the fluids so that the beds of the material are made and a typical example would be let's say 50 to 300 cycles per minute this is again an example when we think of suspensions, selection of fluids of liquids such that insoluble insoluble solids are fluidized so when we think of insoluble solids that means we will have to select the fluid in such a way that the material does not get dissolved in it and this mixture the suspension is then fluidized. So, that this insoluble material is separated out preferentially. Similarly, when we think of flowing film concentrators we have rift decks, refilled decks and shaking tables and we have flowing water. Preferably the most common fluid that is used is water.

We have flowing water and continuous motion. So, we have the continuous motion along with the stream of water passing through such that based on these motions the flowing water as well as the continuous motion which can be in the direction of the water flow and in the perpendicular direction as well. So, the particles get distributed coarser particles and finer particles and even finer particles will be separated out based on the action of these let us say shaker tables. In dense medium we will have a material of a liquid of known density and these could be of either aqueous nature or organic nature. So, these could be aqueous or organic fluids. Just that we need to decide upon the type of fluid that we are using. Of course, these can be aqueous or organic. One has to think of density and fluid of the specific density and then separate based on these characteristics.

(Ref. 32:30)

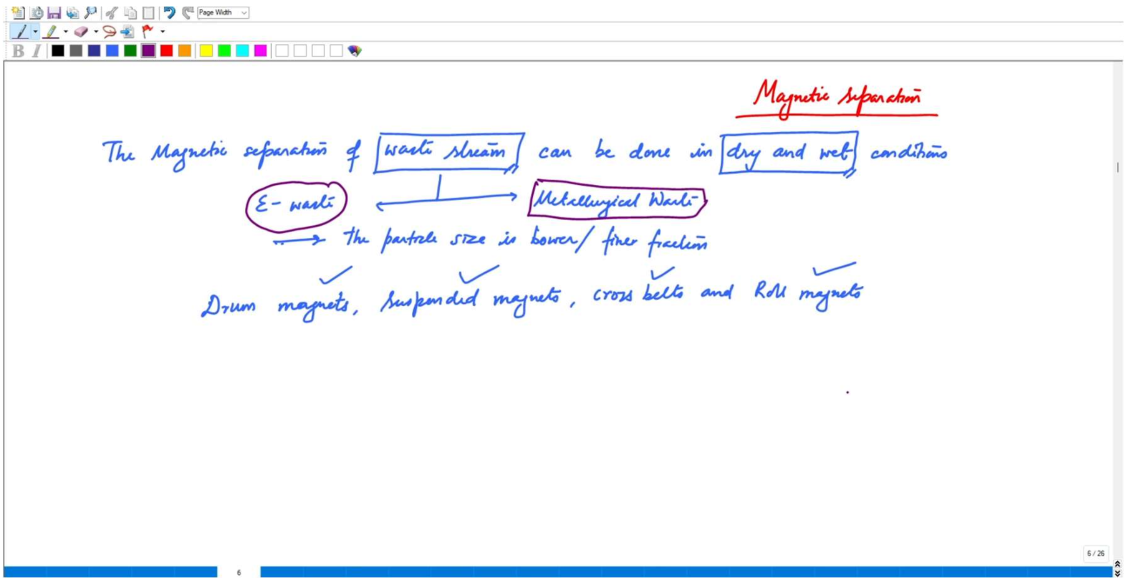


Similarly, we will be looking at magnetic. So when we think of magnetic separation, the magnetic separation of waste stream and of course when we think of waste stream we are already thinking of both type of categories e-waste and metallurgical waste. And again the another assumption that we have made here is the particle sizes the particle size is lower/ finer fraction. So, that the effective separation of magnetic and non-magnetic materials is efficiently achieved, is possible and is efficiently achieved.

So, the magnetic separation of waste stream can be done in dry and wet conditions. What do we mean by dry and wet conditions? In crushing and grinding we can also apply the fluids the most common fluid for crushing and grinding is basically water. So, when we do that we will have a wet grinding wet crushing circuit.

And a similar operation can also be done for magnetic separation. That is why crushing and grinding and separation in dry and wet state. So, we will have various drums. Drum magnets. Suspended magnets.

Cross belts and roll magnets. These roll magnets could be made of rare earth elements. So, these are different types of magnets that could be applied around a given conveyor belt so that the magnetic materials are separated out under the magnetic fields that are being applied due to these magnets. So drum magnets, suspended magnets, cross belts and rolled magnets are commonly used to help and separate out magnetic materials from a given stream and of course we are considering both e-waste as well as metallurgical waste for our studies. **(Ref. 37:00)**



In the upcoming classes, we will be thinking on the lines of developing new processes, studying the advanced literature that are present at our disposal to understand various recycling routes that are present for metallurgical and electronic wastes. Thank you.