Non-ferrous Extractive Metallurgy

Prof. H. S. Ray

Department of Metallurgical and Materials Engineering

Indian Institute of Technology, Kharagpur

Lecture No. # 12

Concluding Part of Module - 4

Friends, I think I have delivered so far some eleven lectures, and in the last lecture, I was winding up discussions on general principles of extraction and refining. After that, I have taken about a month break because I wanted to think what I was doing. Was I doing things right? Could it have been done differently? Is there something I am missing out?

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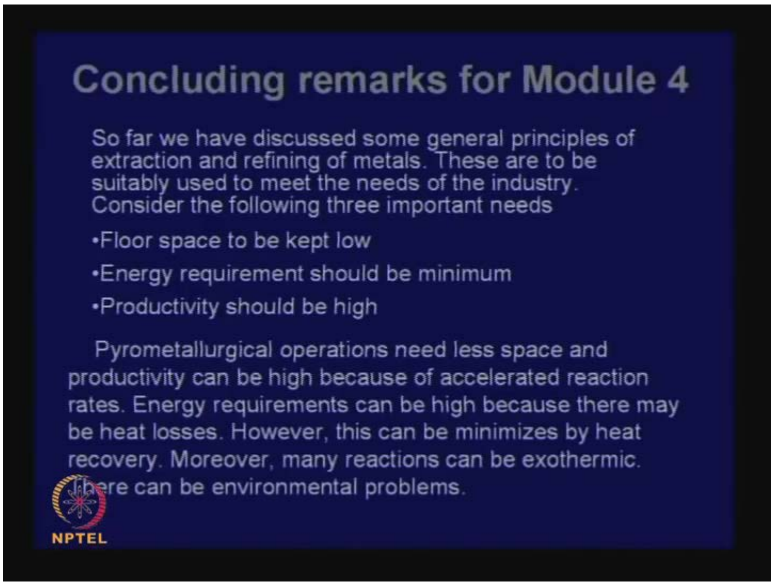

Concluding remarks for Module 4

So far we have discussed some general principles of extraction and refining of metals. These are to be suitably used to meet the needs of the industry. Consider the following three important needs

- Floor space to be kept low
- Energy requirement should be minimum
- Productivity should be high

Pyrometallurgical operations need less space and productivity can be high because of accelerated reaction rates. Energy requirements can be high because there may be heat losses. However, this can be minimizes by heat recovery. Moreover, many reactions can be exothermic. There can be environmental problems.

Now, frankly, I mentioned that before that the way I am lecturing now, it is very different from the way say I would lecture in a classroom, where I have more degrees of freedom; I can walk about; I can look at students who are actually present; I can interact with them. They ask questions. If I make a mistake, I can go to the board and wipe it and restart it.

In fact, I can repeat a class, do it differently, but in this, in this, arrangement, the way I am lecturing now, there are more constrains. I am in one place. There are cameras on me. I have to finish certain things within a specific time slot. There is no room for mistakes. I cannot wipe the board, and therefore, I have to acquire a new experience which I am acquiring. Hopefully, I will do better down. Now, the first question I asked during the break I took was what was it that I was aiming at?

The obviously my aim is to help you learn the subject of extraction of non-ferrous metals. Now, the emphasis is on learning, not on my teaching. I can assume that I am teaching a lot of things, but if you are not learning, then what is it I am teaching. So, let me tell you something about the learning process. In learning, there are several steps - the first comprise facts, any two have facts about things, because you do not have facts; you do not know things.

Facts, when they are organized properly, give you information, and information is distilled into knowledge. Now, my job as a teacher is to give you some facts; show you how information comes from those facts and help you acquire knowledge from that information. Now, in this process as a teacher, I have to strike balance between facts, information and knowledge. I am suddenly rewind that of a very beautiful statement of the famous English writer, poet T S Eliot. Eliot once said rather lamented where is the information lost in facts? Where is the knowledge lost in information and where is the wisdom lost in knowledge? Actually, T S Eliot said the last two sentences. I have added the first one because it is just as relevant.

The meaning of this is that, if you have far too many facts, then you miss out one information. The information you need is merged into a mass of things, facts; some of which may not be necessary. Again, if you have far too much information, it becomes difficult to acquire knowledge out of it. And you also know that there are many people who have a lot of knowledge but they are not to wise. Now, what is wisdom? Wisdom is application of knowledge. This is not what I am going to try to teach you because wisdom as to come from within you. You have to learn how to apply the knowledge you acquire.

So, as a teacher and I am not a guru; guru gives you wisdom. As a teacher, I can give you facts; I can show you how facts go to information. Then, show you how information goes to knowledge and all stop there. So, if you acquire a bit of knowledge, I will be very happy.

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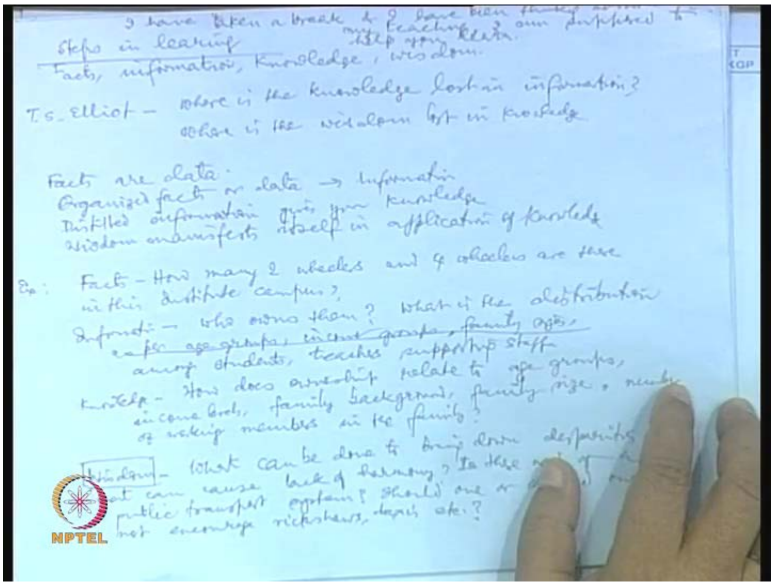

I have taken a break & I have been [illegible] own [illegible] to my teaching [illegible]

Steps in learning

Facts, information, Knowledge, wisdom.

T.S. Elliot – Where is the knowledge lost in information?
Where is the wisdom lost in knowledge

Facts are data.
Organized facts or data → information
Distilled information gives you knowledge
Wisdom manifests itself in application of knowledge

Ex: Facts – How many 2 wheelers and 4 wheelers are there in this Institute campus?

Information – Who owns them? What is the distribution e.g. per age groups, income groups, family ages, among students, teachers supporting staff

Knowledge – How does ownership relate to age groups, income levels, family background, family size, number of working members in the family?

Wisdom – What can be done to bring down disparities? Is there [illegible] What can cause lack of harmony? [illegible] public transport system? Should one or [illegible] not encourage rickshaws, taxis etc.?

Now, let me give you some example about how, what is the distinction between facts, knowledge and facts information and knowledge. Imagine that I want to study the, the, kind of vehicles - two wheelers and four wheelers that are there in this campus and the role they play in the society. Now, you can always get some volunteers to acquire information about facts, not information, facts about two wheelers and four wheelers. They stand in strict corners; they go from house to high house; they go to the registration authority where vehicles are registered and they get a total information on how many two wheelers are there; how many four wheelers are there and so on.

Now, they can also acquire a lot of unnecessary information, which perhaps are now required like how will the vehicles are; what is the condition of the vehicle; what colour they are, etcetera, etcetera. We do not want that. What I, what I, want, I will tell you later.

Now, when you have whole lot of data about the ownership of two wheelers and four wheelers, you cannot distill the information; distil this, these fact into in an organize manner to get some information like you can find out about the ownership of these two wheelers and four wheelers. How many students on two wheelers or four wheelers? How does the ownership depend on age groups, income levels, spread across students, teachers and supporting staff? How it depends on the number of people in the family who have regular income etcetera, etcetera, etcetera.

Now, when you have get this sort of things, when you have organize the, the, facts into a higher level, then you get information; then we try to get a knowledge that, let us analyze the disparity in ownership of vehicles amongst different income levels, different social strata and the implications of these. There will be some disparity. Is it right? Is it wrong? Should we bring in public transport system? Should we bring in more rickshaws? Should we bring in buses? This will depend on practicality, on traditions, what is tolerated in the society.

Then we are going towards to knowledge as to how we best utilize the information we now have from facts to bring in more harmony, more justice, etcetera, etcetera, in the society. That will be knowledge. Now, in the industry also there are lot of facts. If you go to any industry, you will find there are recording instruments which are constantly measuring things. There are some people whose job is to collect facts and stop there.

Then there a higher level a person will come who organize these facts into information that go to executives who from the information acquire knowledge. Now, in that process, you will find one has to decide on how to handle contradictory requirements. In a society, in a family, in an industry everywhere, there are contradictory requirements means, if you want to do this, then something else suffer; then you have to find out what is the compromise.

Now, I think I am becoming little more philosophical. So, I will bring it to similar questions in an industrial setup, and for that, I thought I will give take two more lectures as concluding remarks for the module 4 which I was discussing last time. So, let us look at the first line, which is about concluding remarks for module 4. Now, so far we have discussed some general principles of extraction and refining of metals. These are to be suitably use to meet the needs of the industry taking into account contradictory requirements, the actual situation prevailing, etcetera, etcetera, etcetera.

Now, there are three very important requirements for in industry, and they are: floor space, energy requirement and productivity. Not that these are the only requirement. There are other requirements, for example, capital, labour, environmental problems, many other things, but let me restrict myself to three questions - the floor space to be kept low; energy requirement should be minimum; productivity should be high.

Now, if you consider pyrometallurgical operations, it is quite obvious that they need less space and productivity can be high because very often use reactors of furnaces which operate at high temperature, and at high temperature, reaction rates are accelerated, but then, when you are operating at high temperature, energy requirements can be high because there may be heat losses. Of course, in many pyrometallurgical operations, heat is also recovered from the gases that are coming out as hot gases.

This will minimize the heat requirement if you can recover the heat. Secondly, contrary to what we may think that all pyrometallurgical operations need a lot of heat. There are also many reactions which are exothermic. For example, we will consider when we have to go to copper metallurgy. When you roast copper which requires high temperature, by roasting is exothermic. It almost proceeds by itself if you do not allow too much of heat losses.

Smelting, next step, or after that, we will come to bliss the copper formation. They are all exothermic. In theory, everything can be done without supply of external heat, but that is not possible, because in practice, there will be heat losses, but anyway, in generally, you should think that in pyrometallurgy, you are operating at high temperatures. So, obviously, one should think that energy requirement should be high, but then space will be limited, because in a small reactor, simply by increasing the temperature, you can produce a lot. Not that you can go on increasing the temperature; you cannot do that. There are there many limiting things. For example, one limitation are the refractories. Refractories cannot take more that a certain temperature level.

Secondly, you do not need all kinds of unwanted reactions. If you go to very high temperatures, things may happened which you do not want to happen. So, not that the upper temperature is unlimited, but we can go to high temperatures actually with reaction widths.

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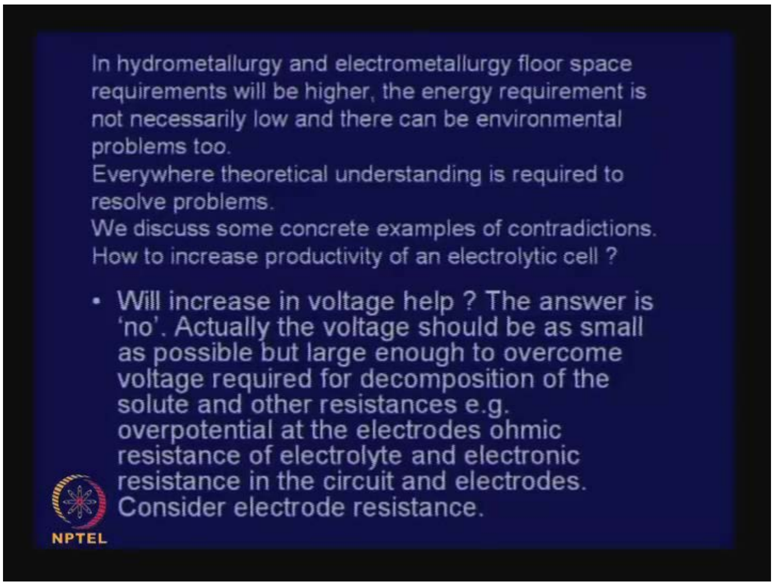

In hydrometallurgy and electrometallurgy floor space requirements will be higher, the energy requirement is not necessarily low and there can be environmental problems too.
Everywhere theoretical understanding is required to resolve problems.
We discuss some concrete examples of contradictions.
How to increase productivity of an electrolytic cell ?

- Will increase in voltage help ? The answer is 'no'. Actually the voltage should be as small as possible but large enough to overcome voltage required for decomposition of the solute and other resistances e.g. overpotential at the electrodes ohmic resistance of electrolyte and electronic resistance in the circuit and electrodes. Consider electrode resistance.

Now, compare that to hydrometallurgical electrometallurgical operations, which are, consider first hydrometallurgy which is always near, near, or below 100 degrees because we are using hydro-medium. Also in electrometallurgy, you can have aqueous electrolysis. There also temperatures are low, but these cannot be done in very limited spaces, because when you are handling liquids, you need pipe lines; you need plumbing; you need floor space and also because a temperatures are low. Reaction rates cannot be high. So, the space requirement will not be low; space requirements will be high.

Now, all these can be understood through common sets, but you can bring in some amount of quantification, also bring in a bit of theory. I will, I will, try to give you some examples of that. How we can be more rational when you make statements like this. We will also discuss some concrete examples of contradictions. Now, let us start with by considering an electrolytic cell. Now, in electrolytic cell, you apply a voltage; you pass some current. Voltage into current is the energy requirement and you produce the metal.

Now, the first question is - will you produce more metal by giving more energy through increase in voltage? You increase voltage. So, more energy voltage into current would you produce a more metal? The clear answer to that is no, because there amount of metal you are going to deposit on the cathode as nothing to do with a voltage. It is according to Faraday's laws governed only by the current that is being fast, and Faraday give two laws - one is amount is directly proportional to the current passed and it is proportional to the equivalent out of the metal.

We need a voltage simply to make possible to dissociation of the solid, and there are the idea is to keep voltage to the minimum. We need only the voltage that is required for dissociation of the solid. Unfortunately, we always need to have some excess voltage because voltage is also required to overcome the resistance of the electrolyte, the electronic resistance in the circuit and the electronic resistance in the electrodes themselves.

Now, when the electrolysis takes place at a higher temperature, then the resistance of the bath used, is used to generate heat because there, there, will be a voltage loss. There is a resistance of the electrolyte; a current is going through and there is an I square r amount of energy. That is not lost really, but that is what keeps the melt hot. So, why you need a voltage? For dissociation of the solids would also need for high temperature electrolysis, certain amount of voltage to be lost for heating of the electrolyte. This you will not need for room temperature electrolysis.

Now, all these can be analyzed very rationally using simple theory. I cannot go into all these, but I will discuss something which common sense tells us, but we can prove it little bit of mathematics, that is, suppose I have an electrode. Now, you know the electrode surface where the metal is dispositive. That area is very important. The larger the area, the more metal can be dispositive. So, there is a concept of limiting and the current density, current pass per unit area of the electrode. If the area is may be very large, there can be a more current; so, more metal can be deposited.

Now, the electrode area can be increase in many ways. The electrode can be made very wide or it can be made very deep. Now, if you make an electrode which is very wide like the black board say in the horizontal black board, area is very large, but if you do that, you are taking more floor area. So, suppose somebody says why not put the black board the other way. So, that it is a very deep we goes below ground; you dig it below ground or make the cell vertical; make a long high electrode. Can we do that? The answer is no.

We can show while through very simple logic that, if you make the electrode very tall, then you are going to increase its resistance for too much. So, you will be losing voltage there and that voltage does you nothing; it is simply heats of the electrode. Necessarily, the electrode has to be wide and not tall.

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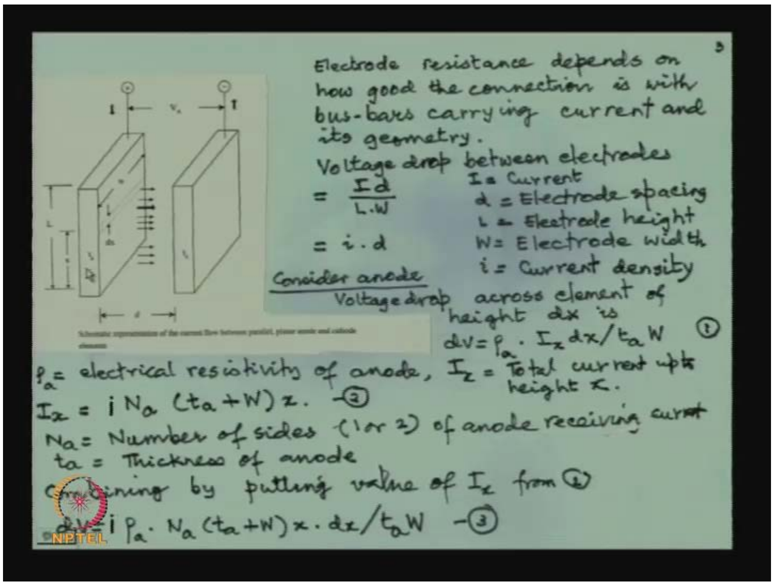

Electrode resistance depends on how good the connection is with bus-bars carrying current and its geometry.

Voltage drop between electrodes

$= \frac{Id}{L.W}$

$= i.d$

I = Current

d = Electrode spacing

L = Electrode height

W = Electrode width

i = Current density

Consider anode

Voltage drop across element of height dx is

$dV = \rho_a \cdot I_x dx / t_a W$ ①

ρ_a = electrical resistivity of anode, I_x = Total current upto height x.

$I_x = i N_a (t_a + W) x.$ – ②

N_a = Number of sides (1 or 2) of anode receiving current

t_a = Thickness of anode

Combining by putting value of I_x from ②

$dV = i \rho_a \cdot N_a (t_a + W) x \cdot dx / t_a W$ – ③

How do we prove that? Let us consider. We will consider two electrodes sitting side by side, and the current is these are the current feeders. Let us consider the anode. Current comes from the top and it flows towards the cathode. Now, let us call this distance x; the distance to which if the current is traveling and the elemental distance is dx. We call the width w. The total height length you can call it is l and the thickness t a - thickness of anode.

Now, let us analyze this situation simply to find out wire resistance will be higher. Will it be higher if this dimension is very high or if that dimension is very high? Now, electrode resistance, I have written here, depends on how good the connection is with the bus-bar carrying current and its geometry. This we are going to ignore means how it is connected. Here, this connection is also vital important in industry because that will be part of electrode resistance. Let us ignore that. That is a technical problem that you must find ways of connecting this electrode to the feeder in a way so that there is very little resistance in the connection, but once you have done it, the voltage drop between electrodes will be what? It will be I into d by L W.

I is the total current; d is the distance between them and L W, L W, gives you the total area in the electrode, and this we can write as I d - where I is the current density. Now, consider voltage drop across only this part of it that has you come down voltage of across an elemental dx. Let us assume.

Now, there we first make an assumption that the current density is independent of the height means same amount of current is flowing per unit area. This is exactly not right; there is small error in this assumption to this. I will come to the later on. Now, the voltage drop across an elemental height dx is dv elemental voltage drop rho a, that is, resistivity of the anode. I x total current and dx total current is coming through this divided by t a w. That is the total area.

Now, what is I x? I x is nothing but current density into n a means on how many sides it is acting? Now, there are cells where only one side is active. There are reasons other side is active. This can be 1 or 2 t a plus w; t a plus w gives you this by this the cross section through which the current is flowing into x; it is the elemental height.

Now, substitute for I x from here. So, we will by combining these two equations, get a an equation which is elemental dropping voltage across the dx is current density into resistivity into number of size of the electrode in operation t a plus w. That is the cross section available into x t x divided by t a w. Now, note here generally the thickness is very small compare to the width. So, we are going to ignore t a in comparison to w.

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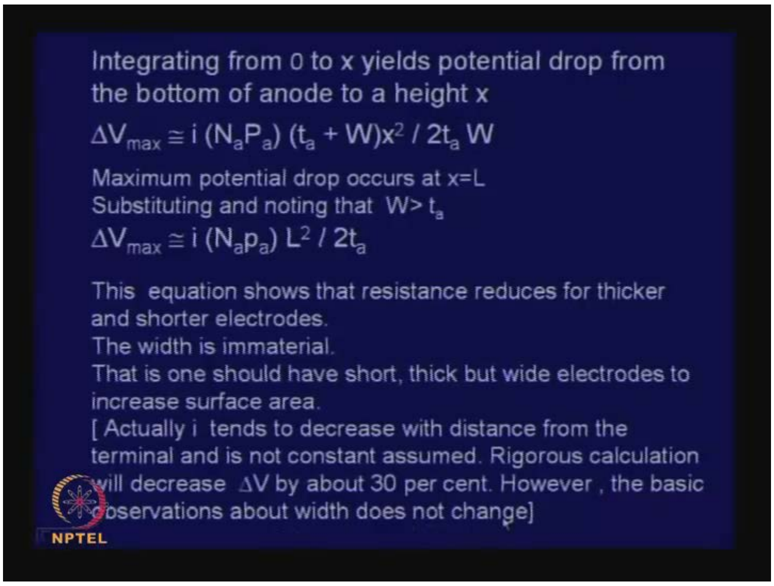

Integrating from 0 to x yields potential drop from the bottom of anode to a height x

$\Delta V_{max} \cong i\ (N_a P_a)\ (t_a + W)x^2 / 2t_a W$

Maximum potential drop occurs at x=L
Substituting and noting that W> t_a

$\Delta V_{max} \cong i\ (N_a p_a)\ L^2 / 2t_a$

This equation shows that resistance reduces for thicker and shorter electrodes.
The width is immaterial.
That is one should have short, thick but wide electrodes to increase surface area.
[Actually i tends to decrease with distance from the terminal and is not constant assumed. Rigorous calculation will decrease ΔV by about 30 per cent. However , the basic observations about width does not change]

Now, if we integrate from 0 to x, we get the total potential drop from the bottom of the anode to a height x and that comes as delta v is equal to this. Now, maximum potential drop will occur at x equal to l means of the, of the, terminal and substituting and noting the w is greater than the thickness. We get finally a, an expression for the voltage drop maximum across the entire heights of the electrode as this. I is the current density; N is the number of sides that are relevant 1 or 2. This is resistivity should actually be a rho l square is the length square divided by 2 t a, which is the thickness of the anode.

Now, you see in this equation, there is no width means width does not play a role in increasing or decreasing the resistance of the electrode, which means you can make it as wide as you can. Increase the area of the electrode that to increase the width; it is not going to change the resistance.

On the other hand, l square this is a big culprit l the resistance increases in proportional to square of the height of the electrode. So, obviously the equation shows that the resistance reduces for thicker electrode. This we know which always there is a thicker electrodes and shorter electrodes the width is immaterial.

So, what does the industry do? The industry simply cannot have very deep electrolytic cells; it does not mean there will be minor screw. There are some practical things after all. You cannot take electrode which is only this high and the 10 meters wide no, but by a large, the height has to be limited; width can be broad because the width is not adding to the resistance and the, the, electrode should be thick, thick, and wide.

Now, I have refer to this that I mean the current that is coming and flowing to the other electrode that current per unit area actually changes as it goes down the electrode and rigorous calculation shows that delta v will change by about 30 percent. It will change about the, however the basic observations about the width does not change.

Delta v according to final calculation change, but it still immaterial; width, width, is immaterial. So, the final conclusion will come to this is this that all electrolytic cells will have to have thick electrodes as thick as possible. They will have to be shallow as shallow as practical book and they have to be wide in terms of the electrode width as wide as practical limit.

Now, there are practical limitations everywhere and that is the industry as to decide where is the optimum from the point of view of operational facilities practically it is a production etcetera, etcetera, etcetera. But someone substance is the since you are going for width and not for depth, you are going to take more floor area; you cannot do the operations in a small floor area.

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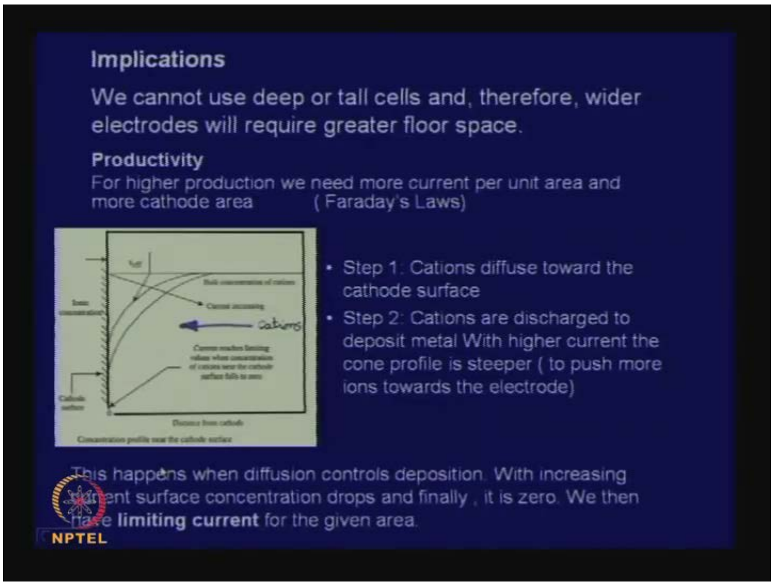

Implications

We cannot use deep or tall cells and, therefore, wider electrodes will require greater floor space.

Productivity

For higher production we need more current per unit area and more cathode area (Faraday's Laws)

- Step 1: Cations diffuse toward the cathode surface
- Step 2: Cations are discharged to deposit metal With higher current the cone profile is steeper (to push more ions towards the electrode)

This happens when diffusion controls deposition. With increasing current surface concentration drops and finally , it is zero. We then have **limiting current** for the given area.

So, these are the implications; we cannot use deep or tall cells, and therefore, wider electrodes will acquire greater floor space. Now, let us talk about productivity. We can increase the productivity by making the electrode wide. That is one way because the wider the area or rather bigger the area, more current can be used to deposit more pulp metal on the electrode surface, but then there is a catch again. There is a maximum limit to which you can increase the current for as given area of the electrode just because you have an electrode area, and the Faraday's laws says more current means more metal production. You cannot go on increasing the current. Why you cannot do that? To understand that, we have to find out; we have to analyze the mechanism of depositions. See, here is an electrode surface and current is bringing metallic ions to this cathode for deposition. It is a negative electrode; positive ions are coming to deposit.

More current means greater flux of metal ions that per unit time, more number of ions are coming. So, increase the current means more and more ions are coming. Now, when the ions come, they have to get discharged at the surface. From metal ions, they have to become metal deposit, and so, the process of depositing metal on an electrode. During electrolysis, it has two step process - the first is diffusion of metal ions to the surface; then discharge of metals ions at the surface. These are two distinct steps.

Metal ions come through the bulk of the electrode because the current is pushing it. It gets discharged by a reaction where metal ions take up electrons and get them so depositor. So, we have a diffusion step and ion exchange and electron exchange step. Now, it is so happens that in most cases, the second step is fast means the moment metal ion comes to the surface; it gets discharge a metal deposits.

So, in such this situation, we called diffusion controlled reaction. So, the rate does not depend on the rate of transfer of charger the surface. Rate depends on the rate at which it is coming through the solution through the electrode and that should diffusion. How does it happen? It happens because of this that this is the surface of the electrode; this is the bulk. Current is pushing the ions towards the surface, and as it gets discharged, it is concentration at this surface drops. So, you have a concentration profile, and because of this concentration gradient, diffusion takes place.

Now, when you want to increase the rate of diffusion means rate of transfer of metal ions to this surface. What happens is, this profile changes means you have a greater gradient here, because unless you have a greater gradient, you cannot have a greater diffusion flux, but then, as you increase the current, surface concentration drops to make the gradient steeper to allow greater diffusion rate, but there is a limit, because when you increase the current for too much and to sustain that, the surface concentration drops at some stop; it drops to 0.

Means now you are passing so much of current, and to sustain that, there is so much of gradient now, because unless there is a gradient, there cannot be diffusion. Now, at this surface, you have brought it down to 0. This is the limiting current because one it falls to 0, you have a limiting gradient and that limiting gradient defines how much current you can send. This becomes the limiting current and limiting current divided by the area of the electrode becomes limiting density.

So, in any cell, your first goal will be to increase the surface area. Having increasing the surface area, your goal will be to increase the current, so that you can produce more metal. As you increase the current, how will the current be sustained, because it is a diffusion controlled process; there will be a more gradient, but beyond the certain level of current, the surface concentration of metal ions falls to 0. It is nothing left, and therefore, it cannot go turn any further that is the limiting current density.

So, in any given cell, if it is a diffusion controlled process which most metal deposition processes, there are, there is a limit and this limiting current concept is a vital importance in electrometallurgical operations. So, I will quickly go through again. This higher production we need more current per unit area for more cathode area. Step one is cations diffused towards the cathode surface; step two is cations are discharged with the deposit to deposit metal. With higher current, the concentration this should be see concentration profile is steeper to push more ions towards the electrode, and then finally, we end up with the limiting current.

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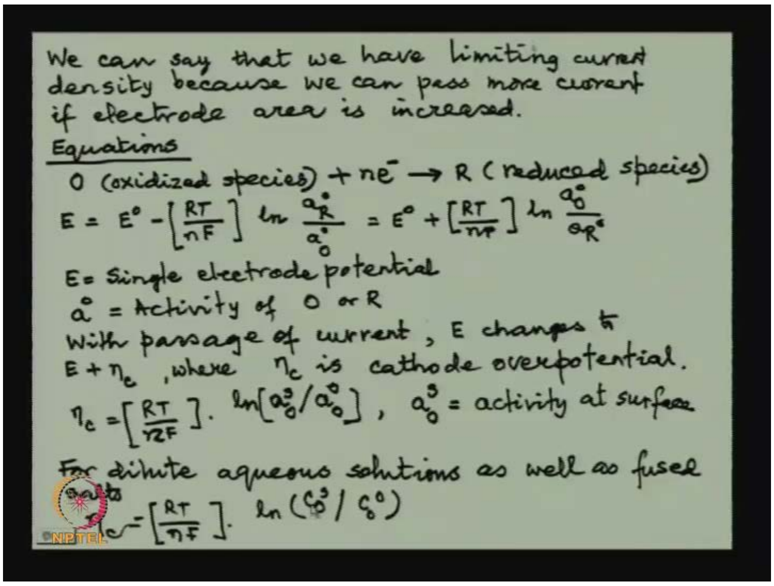

We can say that we have limiting current density because we can pass more current if electrode area is increased.

Equations

O (oxidized species) + $ne^- \rightarrow$ R (reduced species)

$$E = E^\circ - \left[\frac{RT}{nF}\right] \ln \frac{a_R^\circ}{a_O^\circ} = E^\circ + \left[\frac{RT}{nF}\right] \ln \frac{a_O^\circ}{a_R^\circ}$$

E = Single electrode potential

a° = Activity of O or R

With passage of current, E changes to $E + \eta_c$, where η_c is cathode overpotential.

$\eta_c = \left[\frac{RT}{nF}\right] . \ln[a_O^s / a_O^\circ]$, a_O^s = activity at surface

For dilute aqueous solutions as well as fused salts

$\eta_c = \left[\frac{RT}{nF}\right] . \ln(C_O^s / C_O^\circ)$

Now, suppose we have a electrode now and there is a limiting current. What you do? This question has been asked by many scientists in many ways, but before I go to that, whatever I have said let me put it down mathematically because these are all subject to mathematical analysis. We can say that we have limiting current density because we can pass more current if electrode area is increase, not otherwise. What are equations? Basically an oxidized species let say metal ion is at the surface acquiring electrons to produce a reduced species.

The potential for that is given by the Nernst equation. Why you can reverse that and put it this way also - where e is the single electrode potential; a is activity of oxidized or reduce species. With passage of current, e changes to e plus eta c. This eta c is what you call the cathode over potential because the potential depends on metal in concentration with metal ion.

Now, if the metal ion concentration is dropping at the surface because of the diffusion phenomenon, then the electrode potential will change and the change is the cathode over potential because the process being diffusion control. So, this we can calculate as r t by n f. This, this, is n f long activity of the species at the surface divided by activity of the oxidize species in the 0 or bulk activity at surface. For dilute solutions as well as fused salts, this value we can calculate. How will you calculate, because first of all dilute solutions let us replace activity by concentration.

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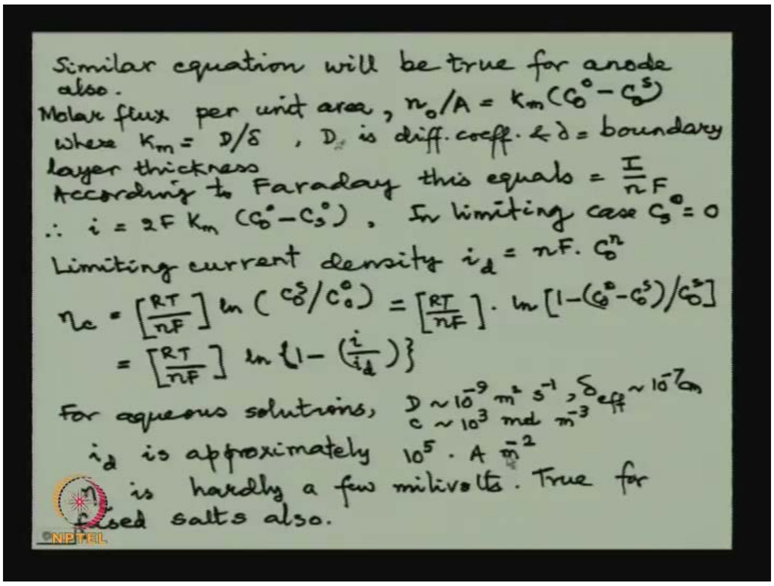

Similar equation will be true for anode also.

Molar flux per unit area, $n_o/A = K_m(C_o^o - C_o^s)$

where $K_m = D/\delta$, D is diff. coeff. & δ = boundary layer thickness

According to Faraday this equals $= \frac{I}{nF}$

$\therefore$ $i = 2F K_m (C_o^o - C_s^o)$. In limiting case $C_s^o = 0$

Limiting current density $i_d = nF.C_o^n$

$$\eta_c = \left[\frac{RT}{nF}\right] \ln (C_o^s/C_o^o) = \left[\frac{RT}{nF}\right] \cdot \ln[1-(C_o^o - C_o^s)/C_o^s]$$

$$= \left[\frac{RT}{nF}\right] \ln\{1 - (\frac{i}{i_d})\}$$

For aqueous solutions, $D \sim 10^{-9}\ m^2 s^{-1}$, $\delta_{eff} \sim 10^{-7} cm$

$c \sim 10^3$ mol m^{-3}

i_d is approximately $10^5 \cdot A\ m^{-2}$

η is hardly a few milivolts. True for fused salts also.

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Now, the similar equation will be true for anode also. Now, molar flux per unit area is total flux divided by a which is the a constant into c naught minus c s naught; c naught is the bulk concentration and c s is surface concentration is the diffusion coefficient, and where a k m is d by delta; d is the diffusion coefficient and delta is the boundary layer thickness. You know, you know, here available diffusion coefficient.

According to Faraday, this equals total current divided by balance into Faraday constant f. Therefore, I that the current per unit area you can get an expression. In a limiting case, when the surface concentration falls to 0, the limiting current density I d is given by this expression balancing Faraday constant and surface concentration in the bulk.

Now, what is then the value of the over potential? We can make substitution and get there expression that the cathode over potential is given by an expression, which is a function of current density and limiting current density. Now, for ecosolutions, diffusion coefficient generally has this value. Delta there is the boundary layer thickness as about this value and concentrations are generally 10 to the power 3 moles per metric cube.

So, I d approximately comes to this that the many processes, the limiting current density is 10 to the power 5 amperes per meter square, per meter square. You cannot pass more than 10 to the power 5. Now, this is very important. There is another thing we can calculate the over potential, but these comes out to be only a few millivolts; this true for fused salts also. So, the phenomenon and over potential does not change the voltage requirement much, which is a good thing. That because there is a over potential, that does not mean that we need to have apply lot more voltage now; that is not require, because there over potential is only a few millivolts, whereas in most cases, you need some volts, several volts by electricity, but what is important is that, there is a limiting current density, and in most operations, you will not be able to pass more than 10 to the power 5 amperes per meter square.

Now, what are the implications? Implications are that if metal deposition is diffusion control, which is the fact in most metal deposition processes. In that case, we change the electrode potential at the surface, but change it very very very little by a few millivolts. So, the voltage requirement is does not change, but that phenomenon gives rise to a limiting current condition and we can calculate the limiting current in most cases to be about 10 to the power 5 a per meter square. So, you see that a simple phenomenon of electrolysis. If you try to analyze it, think little deeply. We come out with this very interesting and vital (( )) and we can do quantification also as I have try to do.

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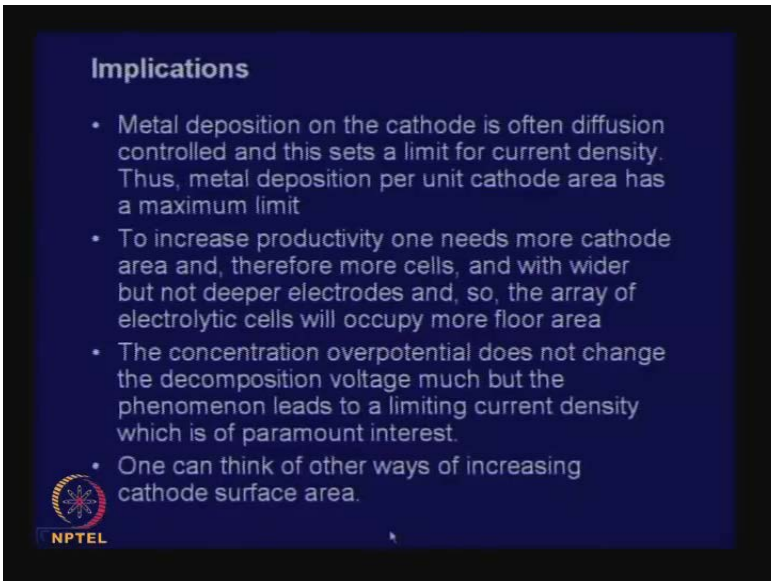

Implications

- Metal deposition on the cathode is often diffusion controlled and this sets a limit for current density. Thus, metal deposition per unit cathode area has a maximum limit
- To increase productivity one needs more cathode area and, therefore more cells, and with wider but not deeper electrodes and, so, the array of electrolytic cells will occupy more floor area
- The concentration overpotential does not change the decomposition voltage much but the phenomenon leads to a limiting current density which is of paramount interest.
- One can think of other ways of increasing cathode surface area.

So, let us summarize the implications now. Implications are that metal deposition on cathode is often diffusion controlled and this sets a limit for the current density. Thus metal deposition per unit cathode area has a maximum limit and that will correspond to 10 to the 5 amperes per meter square. We can calculate how much of metal deposition according to Faraday's law taking into account the equivalent weight. Now, to increase productivity in a cell, one needs more cathode area. Therefore, either you make the cell very wide or have more cells, you can have multiple cells, which means you will need lot of floor area, but definitely you can have wider but not deeper electrodes.

So, generally, we will have an array of electrolytic cells which will occupy a lot of floor area. Fairly, the concentration over potential does not change the decomposition voltage much, but the phenomenon leads to a limiting current density which is of paramount interest, which are repeated many times. One can think of other ways of increasing cathode surface area. Can we change the cathode surface area in some other ways? To this, I will come little later, but before that, let us consider how we arrange multiple cells.

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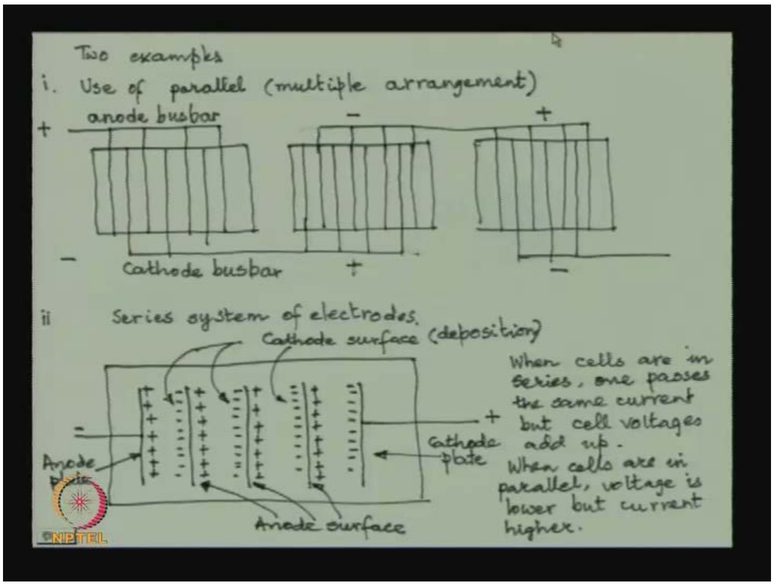

Two examples

i. Use of parallel (multiple arrangement)

ii Series system of electrodes.

When cells are in series, one passes the same current but cell voltages add up.

When cells are in parallel, voltage is lower but current higher.

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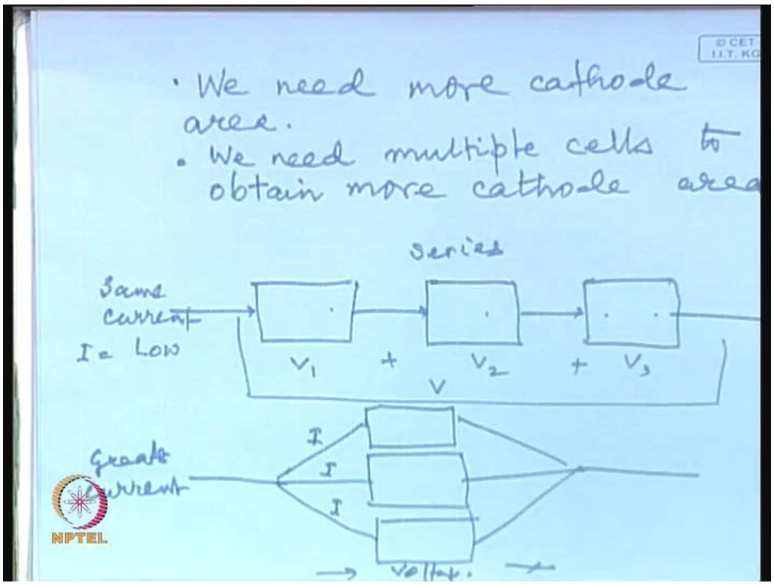

- We need more cathode area.
- We need multiple cells to obtain more cathode area

See, we need more cathode area since we can have only a certain amount of production in one cell. So, we need multiple cells to obtain more cathode area like say for example, we have one electrolytic cell; we have another; we have another. Then, each we have a cathode and anode, and cathode and anode, and cathode and anode. How do we arrange these cells? One will be to have them in series. If we have them in series, then the same current flows through all; one current flows from one will be the other.

So, a current low in the sense as much as you need as for the limiting current density, but the voltages V 1, V 2, V 3 they will add up from here to here. You need get of voltage; the voltage add sum. On the other hand, what you one can do is, suppose you have these three cells; they can be in parallel. What will that mean? This will mean you are feeding current to heat. So, you will need more current here - greater current, but voltage is common between this and this voltage is coming from there is the voltage remains the same.

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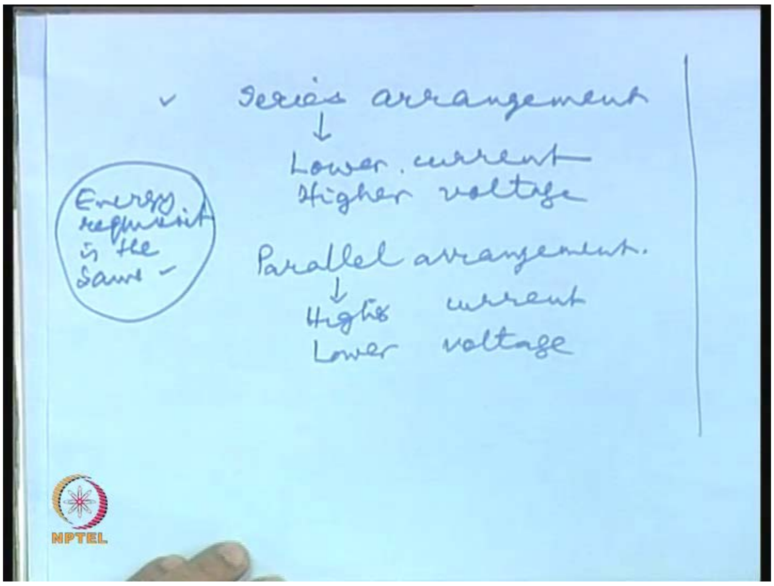

✓ Series arrangement
↓
Lower current
Higher voltage

Parallel arrangement.
↓
Higher current
Lower voltage

Energy requirement is the Same ✓

So, you have a choice between a series arrangement where we have lower current because the same current is flowing through but higher voltage. The voltage is adds up or you can have a parallel arrangements where we have higher current, because the current will get split into different things but you will have a lower voltage, because from two common grids, all of them can be operated. Now, question is this better or is this better?

Now, if you analyze, the power requirement would be the same because power is I into v. Here, I is low; v gets multiply by n into v n i v. Here, current is high; n i voltage is v n i v. The, the, energy is the same, but then, what will the industry do? There you have to take into account practicality and also little bit of common sense. Suppose you put everything in a series arrangements means one after another these cells are in series.

Now, in a series arrangement, the problem is if one cell goes out of water, you want to shut it down for repair, then the entire line is out of operation, get that. It is like if you have a whole lot of clerks are working in an office; a file goes form one desk to another desk, from that desk to another desk, to that desk to another desk. Now, if one clerk takes leave, then the entire chain of operation stops. Which industry cannot allow? There the advantage that you are taking a lower amount of current which is going through along and may be you can do with more voltage.

On the other hand, in a parallel arrangement, if one goes out of order and you need some repair or you need something, then you remove; it does not matter. The others are operating. The current does not go through that with the current goes through the other thing, and that is what is done in many offices also that we never, never, proved everybody in series. We always have a parallel arrangement also a safety valve kind of thing. If this process is not working, the others are working. So, industry would not like you have put everything series, never, but there are advantages.

Now, if you put everybody in parallel, there is a disadvantage, apparent disadvantage. What is the disadvantage that, when they are in parallel, the current that is coming, it is getting split into different stream; so, you need very high current, very high current. Now, very high current means the current losses in the circuit will be I square r; r is the resistant, electron resistance to circuit, which means you may have to reduce the electronic resistance of the circuit. That you can do.

Suppose you are using it is flowing through copper, it has the very thick copper bus-bar, so that the it will depend on the cross section, and therefore, you have to make very thick, provide for very thick wires to go through the current. So, as I said, there are these contradictions that, if you do this, you have one problem here. If you do that, you have another problem here and the man in a industry through trial and error, through their facts, information and knowledge will acquire the wisdom to do what is right.

And what is right? Industry what is right means first of all, what is workable? Operations cannot stop. Whatever is done should be friendly to the technologies available. You can always come up with lot of theories with technology say this is not possible. So, there should be a technology to back up your wisdom. Your operation have flexibility should be there; floor space should be minimum.

So, the industry has to play around with these contradictions and this has been done, but even then, no two plans are alive because there may be somebody who can handle one contradiction better than another industry which has another contradiction there. So, there are many aluminum plants where the arrangements are not all identical. There may be slight differences. When you come to production or actual matters, you will find nothing has been totally systematized. Basic principles are the same because you know, but then, it all depends on local conditions, the talent available, the technology available.

Now, I will continue with this little more that what will industry do? How will they handle this part that you need multiple cells? How will you arrange those multiple cells? This I will consider in the next lecture. And apart from that, suppose you have a given cell which is suffering from a limiting current problem, is that something we can do to increase that limiting current? Think. Thank you very much.