Mineral Resources: Geology, Exploration, Economics and Environment

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Lecture – 58

Environmental Impact of Mineral Resource Exploitation (Contd.)

Welcome to today's lecture. We have started to discuss one of the important topics related to mineral resources as the Environmental Impact of Mineral Resources Exploitation.

And in introductory discussion we saw the spectrum of the impact starting from exploration to the beginning of the mining, the mining processes and the mining of various different types of deposit.

The deposits are pretty wide in distribution. So, there could be metallic oxide mines, there are non metallic mines, but the large class of mines which are essentially the mines of multi metal sulphide deposits. They do pose some additional problems in addition to affecting the landscape, noise and the dust and many of the other environmental impacts that mining activities have.

So, this multi metal sulphide deposits do have some additional deleterious effect on the environment and which are to be properly understood and evaluated. So, we just made a beginning on our discussion on the impact of multi metal sulphide deposits.

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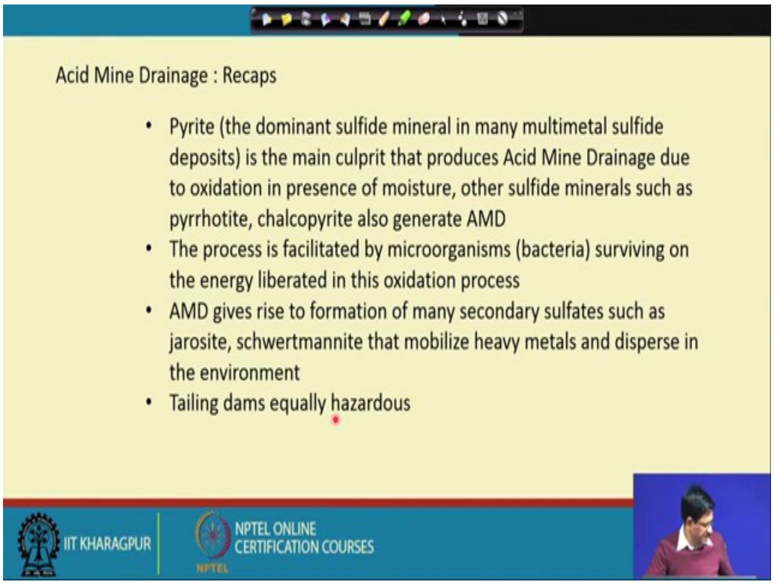

Acid Mine Drainage : Recaps

- Pyrite (the dominant sulfide mineral in many multimetal sulfide deposits) is the main culprit that produces Acid Mine Drainage due to oxidation in presence of moisture, other sulfide minerals such as pyrrhotite, chalcopyrite also generate AMD
- The process is facilitated by microorganisms (bacteria) surviving on the energy liberated in this oxidation process
- AMD gives rise to formation of many secondary sulfates such as jarosite, schwertmannite that mobilize heavy metals and disperse in the environment
- Tailing dams equally hazardous

And we are discussing on the topic of the acid mine drainage or the acid rock drainage.

Essentially, the acid rock drainage originates because of the fact that the ore body which has a good proportion of the mineral pyrite or it is polymorph which is marcasite was being iron disulphide in their composition.

When this ore body is exposed to the surface; the oxygen along with the moisture they react with the ore body which is exposed, the pyrite and generate copious amount of sulphuric acid H2SO4 and which we have seen in detail. Some of the mechanisms of the reactions produce the AMD.

And we also saw the pyrite which is a dominant sulphide mineral in many multi metal sulphide deposits could be called as the culprit because, one mole of pyrite generates four moles of hydrogen ion. Hydrogen plus ion the proton which causes the lowering of the pH or the acute acidity sometimes going to values as low as 1.5 or 2.

And when they get in contact with the surface water or the stagnant water or the running water they adversely affect the biota and the one of the most important aspect is that this particular low acid water which is the acid rock drainage has tremendous solubility of different metals which also gets carried away in the water which is the acid mine water which released in to the surrounding. And generally discharged to the flowing water which is the river nearby.

And the process is facilitated by microorganisms like the thioacidithiobacillus or the acidithiobacillus kind of a bacterial species. There are quite number of such species which are identified. And sometimes the oxidation is also by iron 3 plus where we see that the generation of acidic or h plus ion is still very copious.

And the kinetics of this oxidation process and generation of this acid mine drainage is far more when it is bacterially persistent or bacterially facilitated rather than inorganically. So, the process is facilitated to microorganisms, they survive on the energy that is liberated by this oxidation process.

Because in most of the reactions that we wrote for the oxidation of the sulphide minerals there we did not write how much of energy is released, actually it is quite significant. And the microorganisms which assist such kind of reduction or such kind oxidation of this iron sulphide and release H plus ions and rendering the water very acidic is also they survive in this process.

And the AMD gives rise to formation of a (good number of secondary sulphates and oxide species. Essentially the sulphides like jarosites, schwertmannite and many of the other sulphide species like copiapite ferricopiapite all these minerals which also precipitate from this AMD and give imparting it is the yellow colour which is known as the yellow boy.

The secondary sulphate minerals they can adsorb a good amount of the heavy metals on their surface which we were not dealing them in details. Such kind of adsorption desorption processes for the sake of time. And, but they remain focus of study in many of the evaluation or the environmental impact assessment due to sulphide mining. So, once as you have seen many of these secondary sulphates they get converted to their respective as pH increases and the conditions become more anhydrous; they get converted to their respective iron oxide or, iron hydroxy oxides like goethite which actually releases or which does not possess that much of surface property for a significant adsorption of this kind of heavy metals.

And so, they are again released to the environment and these have to be very carefully monitored to arrive at a conclusion as regards to the impact of the sulphide mining. And additionally the tailing dams which we have not seen them in a much details or we are not able to see them in much details.

The tailing dams are also equally hazardous because there the materials are the discarded material after the beneficiation of the ore. Tthey also do contain minute amount of the sulphides and they get accumulated in huge quantity in the structures which is called as tailing dam or the tailing impoundments.

And they keep on accumulating with their ore water and sometimes they have all the potentials to and they have the conditions which have preparing there is reducing and they do also have the potential to dissolve quite lot of such metals.

And then contaminating the ground water depending on the position of the water table and the area with respect to the tailing impoundment; there can be lot more which could be studied about the a tailing impoundment.

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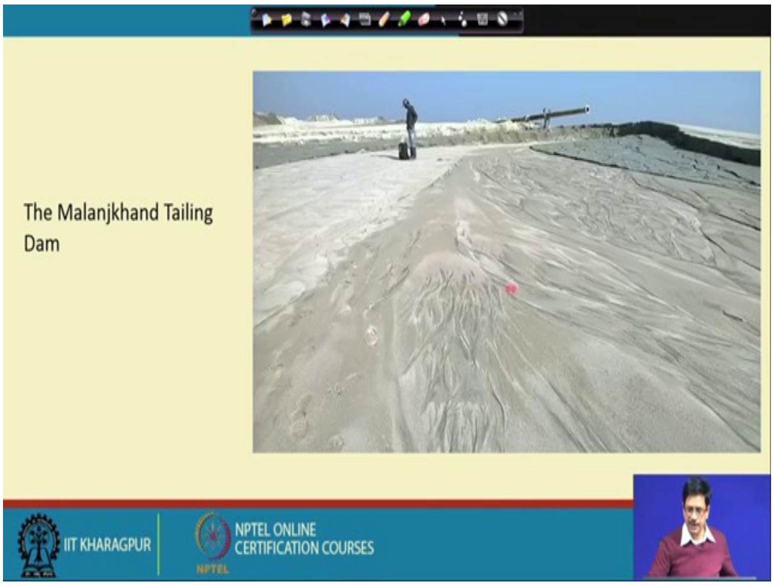

The Malanjkhand Tailing Dam

So, here just for your preliminary knowledge that it is interesting to see this photograph from the Malanjkhand Mines Tailing Dam which the Google map image which I showed in the previous class. What you could see is that the areas which we could see some of the portions like such barriers, which even form there by the coast current, suction of the tailing.

The tailing which is coming is a containing size fractions from clay seems to almost a sand sized particles. And we could see here that this is one of the points at which the thick slurry is getting discharged and this part is a freshly deposited tailing in the tailing dam. And the other parts which are shown here is essentially the part where the tailing has been accumulating for a good number of time.

Now, since this tailing is consisting of all sorts of particle size from clay and silt. So, they do pose a different as a very interesting type of environmental problem here. So, during the dry and the hot seasons these fine particles when this is the part of the dam which is not actively receiving the slurry, the majority part like the one which has shown here. It is a huge area is shown in the Google map before.

So, this part in the very hot and dry seasons and the action of the very hot and very forceful wind, these particles are released in the current as dust or they can be a particulate matter in air. And they can far go to the nearby areas the villages, the water bodies and agricultural fields are all affected by falling of this kind of materials in form of astral and dust by which is contaminate the area.

And so, it is not particularly in case of Malanjkhand; there are other areas where such kinds of tailing dams do contain some toxic metals then the areas will also get affected; where in case of this particular one is not actually known very well.

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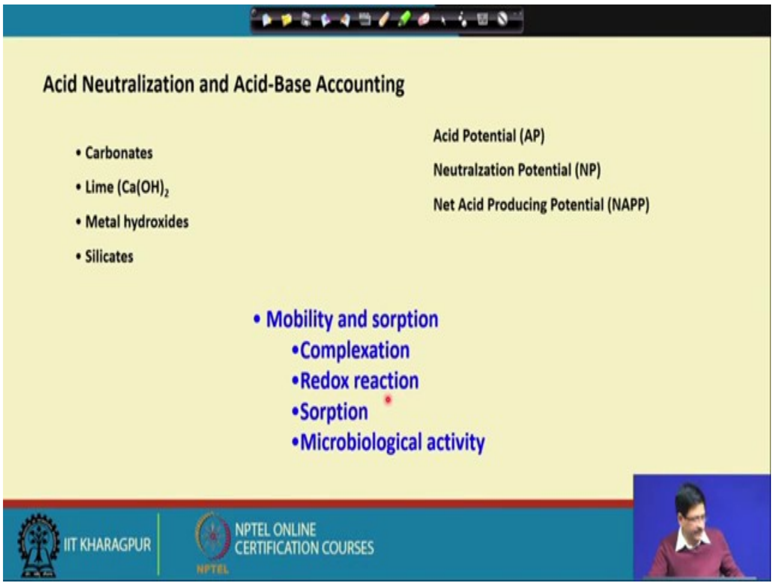

Acid Neutralization and Acid-Base Accounting

- Carbonates
- Lime $(Ca(OH)_2$
- Metal hydroxides
- Silicates

Acid Potential (AP)
Neutralzation Potential (NP)
Net Acid Producing Potential (NAPP)

- Mobility and sorption
  - Complexation
  - Redox reaction
  - Sorption
  - Microbiological activity

So, now we will be just discussing very briefly the topic how do we actually quantify or somehow roughly a semi quantitatively estimates the impact of sulphide mining in the form of the acid mine drainage.

So, if there are acid mine drainage then we always think of that whether there could be always; means to remit them or there are naturally whether there are a situations in which the acid which is being generated can get neutralized.

So, we all know that the acid that is generated acid water can possibly get neutralized. And the neutralization capabilities of which are shown here as there could be carbonates; there could be lime or the metal hydroxides or the silicates in almost decreasing order of their efficiency in the capability of neutralizing the acid water.

So, if there are within the overburden or within the ore body itself within the over burden of the surrounding rocks; if we have a dominants of the carbonate minerals say for example, calcite then it has the capability of absorbing or acting as a sink or the hydrogen ion that is generated.

Similarly in the case of calcium hydroxide, metal hydroxides and silicates more importantly the silicates like the ferromagnesium silicates, even some from the cases like the hornblende or biotite. They do get hydrolyzed by this acidic water and give rise all waste and products and neutralize the water or if there some silicates like potash feldspar they also get altered to clays and could un-neutralize the pH.

So, in the context of the acid mine drainage we generally expressed them in these three different parameters. One is called the acid potential means exactly the way we could quantify that a material which is the ore containing certain percentage of the sulphide minerals. What is its acid potential means how much of acid it will liberate?

And then we will see the neutralization potential means the materials that are present in the ore body; how they will be able to neutralize the acid. And then we would express in terms of net acid producing potential; that means, the neutralization potential. The difference between neutralization potential and the acid potential something will be a net acid producing potential which are needs to be a certain to know that whether a particular mining activity would actually generate acid mine drainage or will not generate, would not that be effective.

So, we know that these are the things that are the complexation, redox reactions, sorptions; that means adsorption and desorption kind of process, microbial activity all controlling these parameters.

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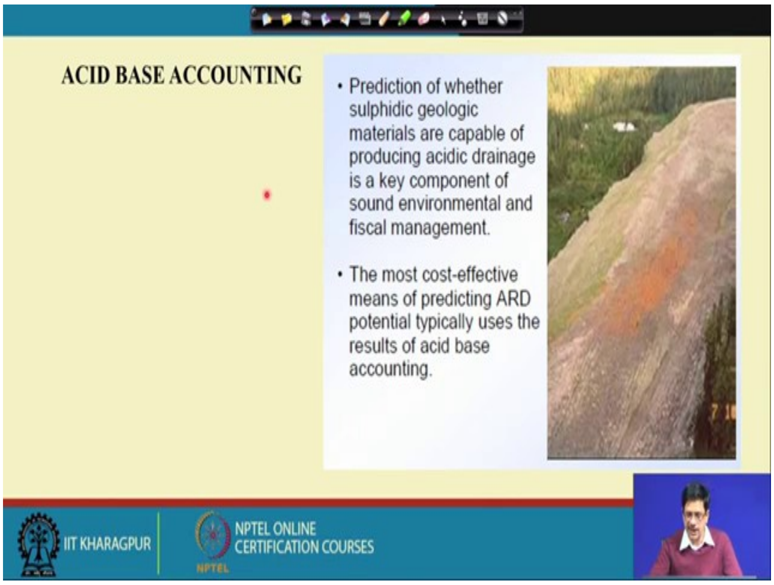

ACID BASE ACCOUNTING

- Prediction of whether sulphidic geologic materials are capable of producing acidic drainage is a key component of sound environmental and fiscal management.
- The most cost-effective means of predicting ARD potential typically uses the results of acid base accounting.

Now, for this kind of environmental impact assessment there are many types of studies which are done. They are the kind of a test which is called as the static tests say acid base accounting is one such kind of static tests. There are kinetic test in which the materials could be studied in the form of putting them in columns and do the experiment in the laboratory.

So, acid base accounting is kind of a static test because it is a onetime experimentation and the result that is obtained can be reported or can be accessed. Whereas, in case of the test which is done with columns where the fluid is made to it, is essentially stimulating a natural condition of acid mine drainage by taking water either distilled water or water of a natural combination.

And then allowing the water to react with the ore for different periods of time and then can monitor that with progress of time how the composition of the water is changing. And such kinds of test are done; there are many other types of tests which are done for actual coordinative evaluation of the acid generation or this acid mine drainage.

So, here the prediction whether sulphuric geological materials are capable of producing acidic drainage is a key component and the most cost effective means of predicting ARD.

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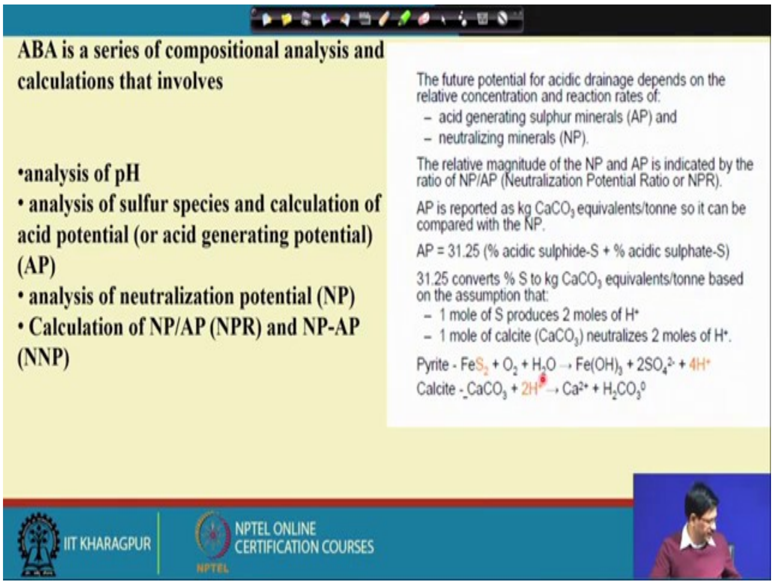

ABA is a series of compositional analysis and calculations that involves

- analysis of pH
- analysis of sulfur species and calculation of acid potential (or acid generating potential) (AP)
- analysis of neutralization potential (NP)
- Calculation of NP/AP (NPR) and NP-AP (NNP)

The future potential for acidic drainage depends on the relative concentration and reaction rates of:

- acid generating sulphur minerals (AP) and
- neutralizing minerals (NP).

The relative magnitude of the NP and AP is indicated by the ratio of NP/AP (Neutralization Potential Ratio or NPR).

AP is reported as kg $CaCO_3$ equivalents/tonne so it can be compared with the NP.

AP = 31.25 (% acidic sulphide-S + % acidic sulphate-S)

31.25 converts % S to kg $CaCO_3$ equivalents/tonne based on the assumption that:

- 1 mole of S produces 2 moles of H^+
- 1 mole of calcite ($CaCO_3$) neutralizes 2 moles of H^+.

Pyrite - $FeS_2 + O_2 + H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$

Calcite - $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3^0$

So, if you could see here that this is series of compositional analysis and calculations which will be involved like analysis of pH. Additionally we do something like getting the material analyse to very fine particle and then getting with deionised water and monitoring the pH of the water which can be reported. So, that gives us a qualitative idea as to for the almost the quantitative idea what kind of a pH we can expect for acid mine drainage.

Analysis of the sulphur species and calculation of the acid potential; here it is mostly assumed that these sulphidic sulphur is the culprit and which generally generates the acid mine drainage. For the sulphate sulphur like say for example, the sulphate being present in the form of gypsum or any other kind of sulphate minerals will not be potentially acid generating.

So, only the sulphidic sulphur will be acid generating and the analysis of the neutralization potential and the calculation of something called a net potential ratio ; this neutralization potential by acid potential which gives us the net potential ratio. And the neutralization potential difference between the neutralization potential and the acid generation potential which gives something like a net neutralization potential.

Now, here the calculation goes like this. So, the future potential for the acid drainage, they depends on the relative concentration and the reaction rates. That is acid generating sulphur minerals, the AP which is the sulphurs and the neutralizing minerals.

Neutralizing minerals has been listed could be carbonates, could be metal hydroxides or could be silicates. So, the relative magnitude of the neutralization potential and the acid potential is indicated by this ratio which is NP by AP which is a neutralization potential ratio NPR.

Now, here the calculation goes like this: The acid potential is reported as kilogram of calcium carbon equivalence per tonne of the material is there in sulphide which can be compared with a neutralization potential. And while calculating the acid potential a factor of 31.25 is multiplied to the percentage of sulphur represent as sulphide sulphur to the to the material.

So; that means, the percent acidic sulphide and the percent acidic sulphate as I said that percent this is almost negligible. So, whatever amount is present a sulphidic sulphur is multiplied by a factor of 31.25 to arrive at a figure which is the acid potential.

So, this also the amount that is required one calcium carbonate equivalent per tonne that is based on. So, if we see this two reactions, the first one is that this is the pyrite then the inorganically induced reaction which is basically given rise to 4 hydrogen plus ion. And in this case we can see that this calcite $CaCO_3$ is consuming 2 hydrogen ions to give rise to calcium and H 2 CO3.

So, here this particular reaction is taken place at a low pH conditions. So, that is able to accommodate the 2 hydrogen ion to give rise to H 2 CO3 and this particular if you calculate the reaction equilibrium we know that what value of pH it will be equilibrated and this value will essentially be value where; that means, the acidity is actually decreased or the pH is increased.

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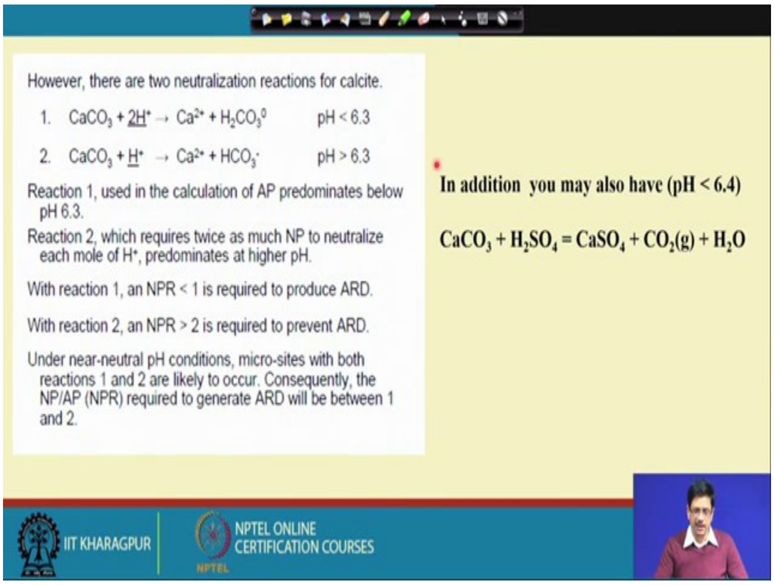

However, there are two neutralization reactions for calcite.

1. $CaCO_3 + \underline{2H^+} \rightarrow Ca^{2+} + H_2CO_3^0$ $pH < 6.3$
2. $CaCO_3 + \underline{H^+} \rightarrow Ca^{2+} + HCO_3^-$ $pH > 6.3$

Reaction 1, used in the calculation of AP predominates below pH 6.3.

Reaction 2, which requires twice as much NP to neutralize each mole of H^+, predominates at higher pH.

With reaction 1, an NPR < 1 is required to produce ARD.

With reaction 2, an NPR > 2 is required to prevent ARD.

Under near-neutral pH conditions, micro-sites with both reactions 1 and 2 are likely to occur. Consequently, the NP/AP (NPR) required to generate ARD will be between 1 and 2.

In addition you may also have ($pH < 6.4$)

$CaCO_3 + H_2SO_4 = CaSO_4 + CO_2(g) + H_2O$

So, this two neutralization reactions; one is calcium carbonate plus 2H is calcium 2 plus H 2 CO3 which happens at an acidic pH; pH is less than 6.3.If that pH is a little higher is more than more than 6.3; then you can accommodate only one hydrogen and will give rise to a bicarbonate ion.

So, as we know that there is a distance difference between the pH of these two fluids. So, reaction 1 used in the calculation of acid potential predominates below 6.3 and the reaction 2 which requires twice as much neutralization potential to neutralize each mole of H plus predominates at high pH.

So, with reaction 1 and NPR of less than one is required to produce ARD. In this case what is the net neutralization potential ratio is less than 1 is required to produce ARD. Where in this reaction 2, a neutralization potential is greater than 2 is required to prevent ARD.

So, the near neutral pH conditions, the micro-sites with both reactions 1 and 2 are likely to occur. Consequently, the NP by AP or the NPR required to generate ARD will be between 1 and 2. So, in addition you may also have pH when it is less than 4 the calcium carbonate would be reacting with H 2 SO 4 give rise to calcium sulphate, carbon dioxide and water which is also an important reaction for neutralization of the acid which is generated.

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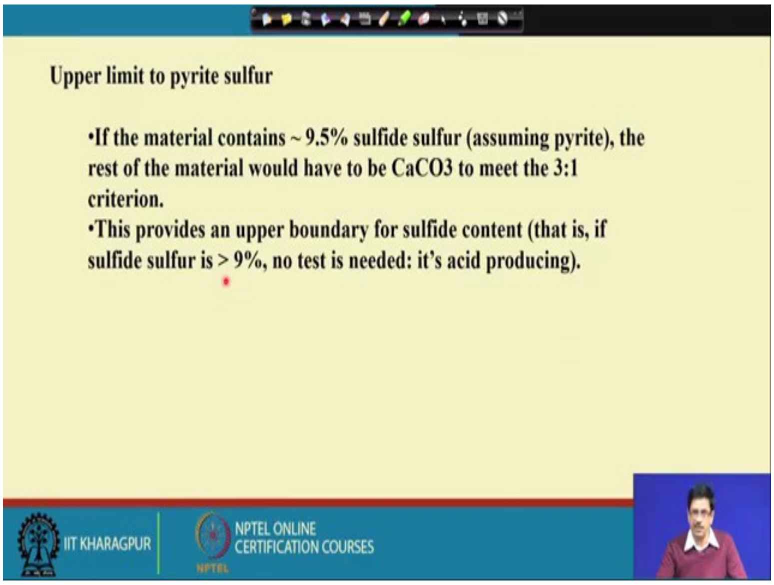

Upper limit to pyrite sulfur

- •If the material contains ~ 9.5% sulfide sulfur (assuming pyrite), the rest of the material would have to be CaCO3 to meet the 3:1 criterion.
- •This provides an upper boundary for sulfide content (that is, if sulfide sulfur is > 9%, no test is needed: it's acid producing).

So, these are the reactions that we can think of. So, this is a kind of a to conclude this topic.. So, there could possibly be a lot more which could be discussed with in connection with acid mine drainage as an impact of sulphide mine mining.

But which involves a lot of exercise and understanding the thing into greater details, solve some kind of process and understanding exactly the methods which we just discussed about the static and the other methods which are involved.

So, here we can just take a rough figure; if the material contains about 9.5 percent sulphide sulphur all assuming to be pyrite rest of the material would have to be calcium carbonate to meet the 3 is to 1 criterion. So, if a particular ore body has the sulphide and then dominantly the host rock to be a carbonate rock then in the ratio of 3 is to 1; then you can safely assume that this particular deposit will not be generating the acid mine drainage. And also and then you take the parameters of your NPR and then it will assign potential ratio.

The acid potential and the neutralization potential ratio and from the value as you would have calculated you could also find out whether a particular ore body is going to be acid generating or not. So, this provides an upper boundary for sulphide content that is if the sulphide sulphur is greater than 9 percent, no test is needed; it is acid producing.

So, it is very simple; the upper boundary of the sulphide. So if the sulphide sulphur in a particular ore body is greater than 9 percent and it is mostly have to be either pyrite or marcasite as we know that all sulphides are not acid producing like galena and celerite kind of mineral they do not generate any AMD. Whereas the sulphides such as the pyrite which generate the AMD.

So, if the sulphide sulphur is greater than 9 percent then there is no test which is needed, it is acid producing. So, we conclude the discussion on the environmental impact of the mineral exploitation in relation to the sulphide or the multi metal sulphide deposits. We will continue our discussion in a next class.

Thank you.