Environmental Remediation of Contaminated Sites
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Lecture – 55
Case Study: Bioremediation

Hello everyone. So again welcome back to the latest lecture session. We have been discussing relevant aspects or we looked at some of the aspects relevant to bioremediation, right. So we will look at or take that further. So again a quick recap of what we have been discussing, let us say, right in the context of bioremediation.

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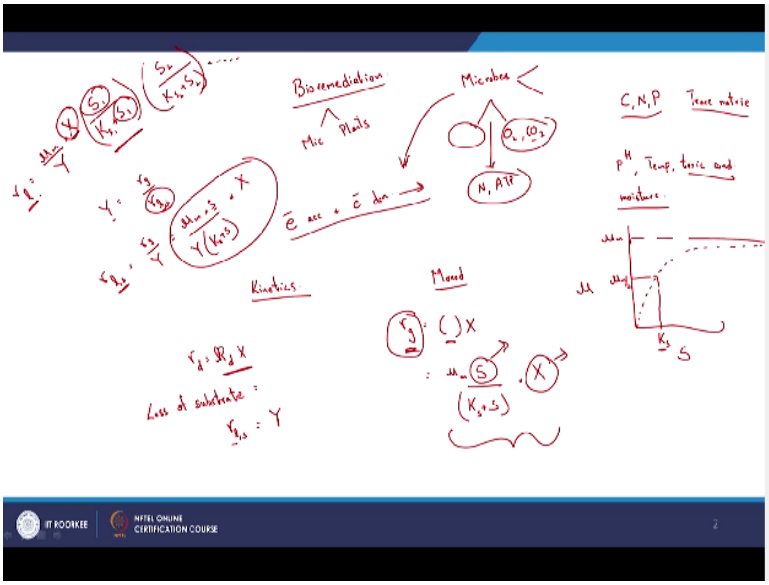

What we look at, let us say, right. So we looked at microbes. We need microbes, let us say. And when we talk about bioremediation, we know that it can be any living organisms. Typically we have microorganisms or plants involved. So when we are talking about microbes, let us say, we can look at native species, non-native species, let us say, that might be introduced or such. We looked at different techniques to measure them, let us say, right, based on growing them, culturing and so on.

Or indirectly measuring them based on oxygen loss or CO2 production or so on. Or, let us say, based on the amount of nitrogen present or the ATP or so on. These are indirectly indicators. And then we also looked at direct measurements of the number of microorganisms present or such, let

us say, right. And then obviously we also looked at the need for the microbes to have an electron acceptor and an electron donor, right.

The redox, this is a redox process. The microbes are going to facilitate this particular redox process, and get there to meet the needs of their particular, what do we say, energy for their growth, let us say, or the cell synthesis, let us say, right. And again obviously rather than just the electron acceptor and donor, we also looked at their other needs as in the need sources of carbon, nitrogen and phosphorus, typically for their relevant cell synthesis.

And then there are some other trace nutrients that they are required to, right. And what are the other conditions or variables that affect the particular microbes, let us say, right. And obviously similar towards pH, temperature, right and toxicity, conditions or toxic conditions if any, let us say, right. And obviously water, there should be moisture; otherwise, obviously microbes cannot thrive, right.

And moisture levels and so on, right. These are the different aspects that we looked at in the previous class, right. And then briefly, we started discussing about the kinetics, let us say, right. Redox process, typically we do not reach equilibrium. It is typically the kinetics or how much time it takes or how fast is the relevant process occurring, let us say, right. That is what is the deciding factor typically, right.

So to understand the kinetics for this particular based microorganism based or catalyzed redox process, what do we look at? Typically we look at saturation kinetics explained by mono-kinetics, I guess, right. And what is it that we have, let us say, right. So, let us say, we if I can use layman's terms here, right or such examples. So we take for, let us say, we grow, let us say, and so on and so forth.

Similarly, microbes, let us say, right. So if I am looking at the rate of growth of the microbes, let us say, and that will be dependent upon, let us say, some factors or variables or constants, let us say, *, what is it now? It will depend upon the relevant concentration of the microbes too, right. And here that is what I have out here, right. And obviously what is this going to be dependent

upon, right?

You are going to now have different factors such as maximum specific growth rate, the substrate, /Ks+S, right and this is what we have, *X. And X is again as I mentioned, more or less the concentration of the relevant microbes, S is the limiting substrate, let us say or which we call as the food for the microorganisms. It can be either the acceptor or donor typically, let us say, right. Again it depends upon the site.

So S is the limiting substrate, typically the food, let us say, that people refer to in the layman's terms, right. So that is the substrate. And typically for the specific growth rate, we have this mu here, let us say. And how does it increase with S, let us say. That is going to have this particular saturation model, right. And, let us say, I have mu max somewhere out here. And this particular, so that mu max/2, we have this Ks, let us say, right.

So again the system is based on saturation model, let us say, and I guess that is what you see out here, the saturation model out here, right. So obviously with increasing S typically, let us say, your system does better. But obviously there are saturation issues here. So the more the food, let us say, and depending upon the concentration of the microbes, you are going to have rate of growth of the microbes now, right.

So typically you are also going to have some decay of the relevant microbes kd*X, let us say, right, rate of decay of the microbes. But again in subsurface system, it is not greatly important, right. So again that is something to keep in mind. But here keep in mind that until now we are only talking about or have referred to, let us say, or have been referring to the rate of growth of the microbes.

But what am I concerned with? I am concerned with the loss or degradation of the relevant contaminant which in this case is the substrate or the relevant food as people say to the relevant microbes, let us say. So I am looking at rate of loss of substrate or rate of loss of the substrate, let us say, right. And that typically is again dependent upon the particular, what do we say, coefficient or it can be explained by particular coefficient, let us say, right.

And that is this particular yield. And what is this give you an idea about? So how much substrate, let us say, or what is the growth of this particular microbe per loss of particular substrate, let us say, right. Or similar to for a given amount of food or contaminant that they consume, what is the amount of growth of the relevant microbes, let us say, right or how are they growing. So that is more or the less the yield out here, right.

So I have rate of, I am trying to calculate this rate of loss of substrate=rate of growth/the coefficients. So that is what I have here. The rate of growth is given out here, right. So that is mu max*S/Y*Ks+S*X, let us say. So this will give me an idea about how the relevant contaminant is being removed, let us say, right. So this is the case when you have 1 limiting substrate, right. So only 1 limiting substrate, that is why you have this out here.

But there are, if there are multiple limiting substrates, let us say, right, that are going to affect the rate step. What is my rate of loss in that particular case, let us say. So I am still going to have mu max/Y*X, right and depending upon the number of limiting substrates, I am going to have additional terms, let us say, right. So this is for 1, for different or more limiting substrates out there, let us say, right, * and so on, let us say, right.

The more the number of limiting substrates, that is how the relevant equation is going to change. But typically maybe you might have seen this equation in waste water, let us say, right, or the cases when you are looking at relevant degradation of waste water, right. And in that case, typically people might have looked at particular, only one particular, what do we say, limiting substrate out here, right.

So again rate of loss of the relevant contaminant is obviously dependent upon the concentration, let us say. And then obviously of the microbes, right. And also the rate of or the concentration of the amount of electron acceptors, donors or the other limiting substrates, let us say, right. So that is what you have out here, right. So that is something to keep in mind. Again X, concentration of microbes.

So as you can see from this equation, the greater the concentration of the relevant microbes, typically the better the performance or faster the degradation of the relevant contaminant, let us say, right. So let us move on. So let us look at some of the important biological process that we have.

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Obviously we looked at respirations, let us say, and fermentations. So let us look at some of the aspects in greater detail. Respiration, what is that about. Typically we have an electron acceptor and an electron donor and you have the relevant process going through to form CO2, H2 and relevant products, let us say, right. So aerobic process, let us say. What do we have out here, right?

So if it is an anaerobic process, what is your electron acceptor typically? Obviously it is typically going to be oxygen, let us say, right. And that is what you see out here. So again in the aerobic process, let us say, you are going to have oxygen and then electron, if oxygen is present in your subsurface, let us say, or in the vadose zone or so on, let us say. Then typically your electron donor is your, what is it now, your contaminant, let us say, right.

And this is what you are trying to remove, let us say, and oxygen is present. So how can you add oxygen, let us say, right. If it is in the vadose zone, there might be considerable amount of oxygen present or by bioventing, let us say, you can introduce some oxygen, let us say. You can

pump oxygen and so on and so forth. Or let us say, if you are going to look at sparging and so on, let us say, that will promote, what do we say, oxygen concentrations in the ground water.

But keep in mind that typically based on the temperature, the concentration cannot be greater than or dissolved oxygen concentration cannot be greater than 10 mg/l, typically anyway, right. So there are limits to these particular, what do we say, maximum concentrations of the relevant dissolved oxygen, right. In that case, what can you do? So you can then look at adding relevant, what do we say, oxygen release compounds as they say, right. So what are some of these oxygen release compounds.

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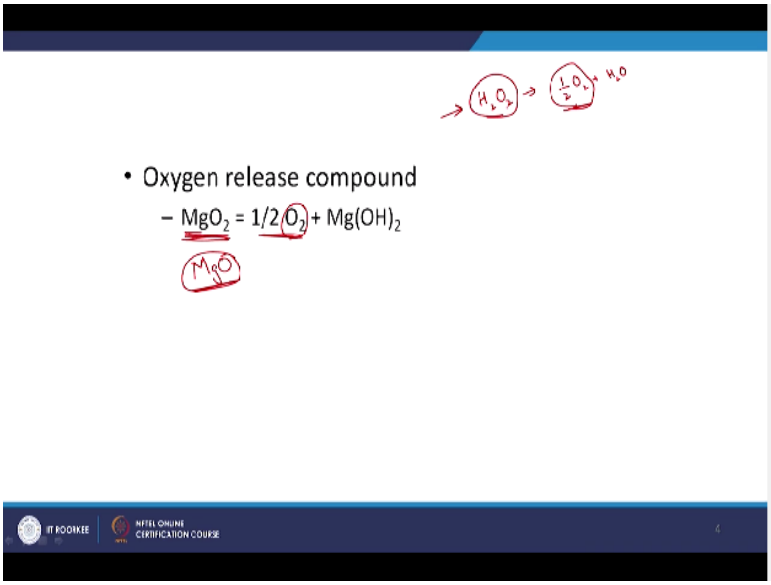

As you can see MgO2 or sometimes MgO2, right, even MgO also and MgO2. But typically this releases oxygen relatively slow. But as you can see here, when you add MgO2, depending upon the amount of, what do we say, MgO2 that you add, you have a reservoir of oxygen. You see that it can dissociate or, what do we say, have again I believe a redox process.

We can maybe look at the relevant oxidation, what do we say, state of the relevant compounds. But again more or less, you end up releasing oxygen, let us say, or providing oxygen. So rather than pumping air through the system, maybe if that is relatively difficult, you can have a source of MgO2 that is pumped into the system, let us say, or introduced into system and that can release oxygen.

Or you can also have hydrogen peroxide, let us say, right. Again that will also release, I believe, oxygen if I am right. If this is the right equation, if I am not wrong. So again hydrogen peroxide too can be used to introduce oxygen, let us say, right. So one aspect to keep in mind is that sometimes maybe while taking a needle syringe or as an antiseptic, right, hydrogen peroxide is also used.

So what does that mean? It is an antiseptic, right. It is going to inhibit or kill the relevant microbes or such if I may say so, right. So obviously you cannot add or should not add hydrogen peroxide at very high concentrations because then it is going to be toxic to the relevant compounds.

So when you are adding compounds like hydrogen peroxide which are strong oxidants or even other compounds, you need to be careful such that you are not exceeding or introducing compounds that are toxic to the microbes, let us say, right. As in if you want to have higher oxygen concentrations, you should not just dump a lot of hydrogen peroxide. Why is that? Because it is going to be toxic to the relevant microbes, right. So there are such different aspects. So let us move on to the other aspects.

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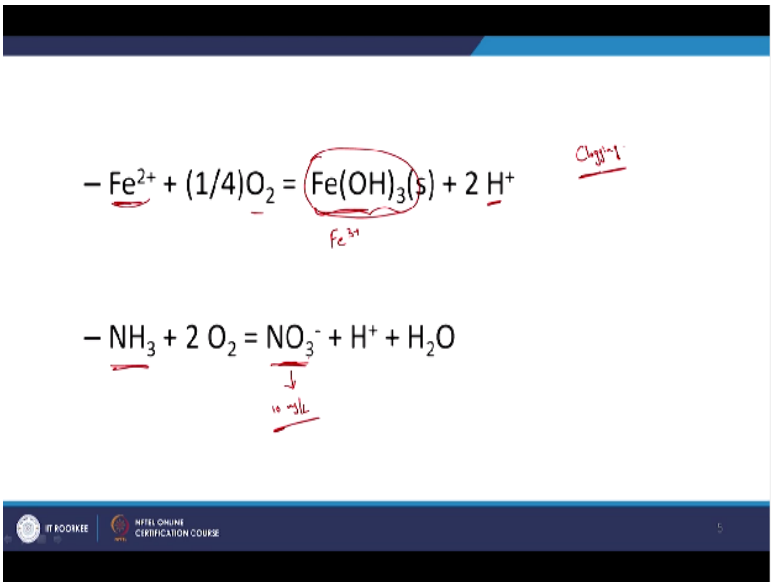

So during these, what do we say, aerobic respiration process, what are some of the relevant

reactions, let us say, right. You have Fe2+, that is oxidized to Fe3+ and Fe3+ being insoluble, let us say, it forms this ferric hydroxide solid and obviously H+, let us say. So what is the relevant issue here? So one aspect is that a solid is formed, right. So typically iron is present in your relevant, what do we say, subsurface.

And if you are adding oxygen or oxygen release compounds, what can happen? You will have this precipitate. So what will that lead to? That can lead to clogging let us say, right. Your relevant pores or such can be clogged now, right. So that is something to keep in mind. And also this iron has an oxygen demand that is what you see out here, right. So these are some aspects to keep in mind.

Or obviously NH3 too can be oxidized to NO3- and keep in mind that NO3- is a toxic compound and I think we have around 10 mg/l, what do we say, drinking water quality standards, let us say, that are required for NO3-. So that might, depending upon the amount of NH3 and the relevant stoichiometry here, you might end up having considerable concentrations of NO3-. Again that is something to keep in mind and act accordingly, let us say, right. So let us move on.

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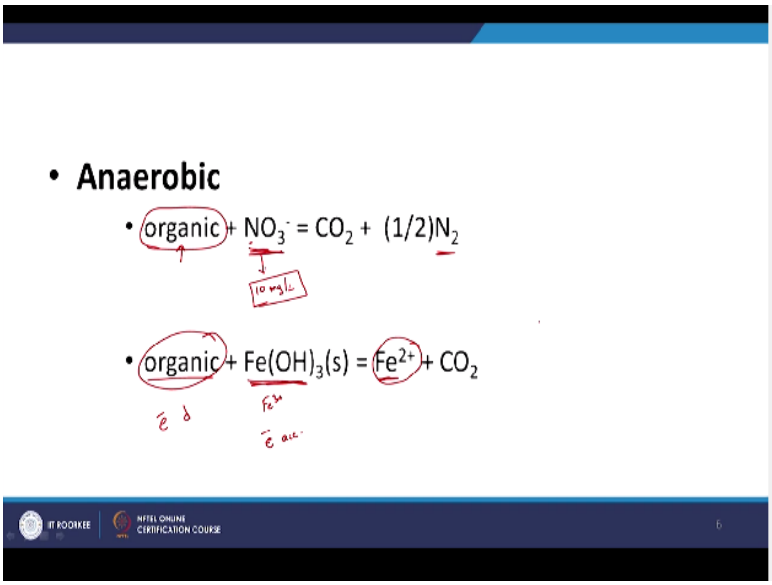

So with respect to anaerobic as in until now we have looked at electron acceptor and donor as part of the respiration process, right, chemotrophs, right that is how they gain their energy. They have different or independent electron acceptors and donors. And here we have anaerobic as in

now the second aspect we are going to look at is the anaerobic phase or the anaerobic aspects, let us say, as in you do not have oxygen.

So what are the other electron acceptors now, right. So you have NO3-, right, oxidized form of nitrogen here and then a reduced form of nitrogen. So if your compound is, the organic compound is your toxic compound, let us say, NO3- will act as an electron acceptor. And you will have degradation of the relevant compound, let us say, right. So that is something to keep in mind.

So you can also think of introducing NO3- to the relevant system if the relevant organic acceptor, organic compound, let us say, prefers NO3-, let us say, for the relevant kinetics or such again based on the relevant microbial activity again, right. So that is something to keep in mind. But again as you mentioned earlier if you are trying to introduce NO3-, keep in mind that we have relevant thresholds drinking water quality standards for NO3-, I guess, right.

So again there are such issues to be concerned about. So again another aspect is the organic contaminant can be, let us say, oxidized by Fe3+, right. So this is going to accept the electron, let us say, and be reduced to Fe2+, right. So that is something that can occur out here, right. And your anaerobic phase, again you have the electron donor and an electron acceptor here, right. So sometimes, let us say, you might not be actually trying to promote this reaction for the sake of degrading a particular organic.

But you might want to promote it, let us say, to be able to release Fe2+ which is a reducing agent that can then reductively dechlorinate any chlorinated solvents, let us say. As in if you have a relatively complex system, these are some aspects that you need to or you might want to look into, let us say, right. So some of the relevant aspects out here, right. So let us move on.

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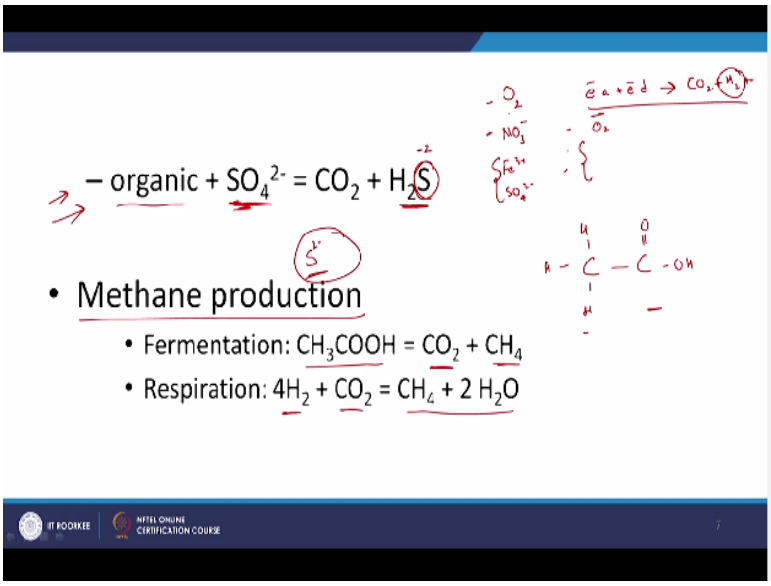

So anaerobic process again different electron acceptors you can also have SO42-, let us say. And again keep in mind that typically energy released is typically higher when oxygen is the electron acceptor, then NO3-, then the Fe3+ system then SO42-, right and then CO2 or the relevant chlorinated solvents, let us say, right. So if you have any of these 2, typically let us say, these cannot act, these as Fe3+ and SO42- cannot act as the electron acceptors, right, that is something that we have discussed.

So again you can have these relevant, what do we say, respiration reactions being promoted by the relevant, what is it now, microbes, let us say, right. But as you can see here, sulfur here, let us say, is being reduced here to hydrogen sulfide, right. Here it is in SO42-, here it is H2S. Here + or -2, let us say. It is in more reduced form. Here it was in its more oxidized form, let us say, right.

You are reducing the relevant sulfur. But what is the relevant aspect? That you are producing S2-, let us say, right. And the key aspect is that S2- forms complexes or typically also precipitates out along with any other metals or some metals or such, let us say. So sometimes you want to promote this reaction because you are forming S2- and that can immobilize by precipitating out particular contaminant or such or heavy metals or metals, let us say, right.

By promoting formation of S2- which is then going to precipitate out along with some other

metal. You are immobilizing the relevant contaminant, let us say, right. So these are some of the aspects again that you can look at or keep in mind, right. So let us move on. So again methane production, let us say, right. Again 2 ways though. Both from respiration and from fermentation. So fermentation, you have only 1 particular compound that is, and from there you end up having a more oxidized and also a more reduced form of the relevant compound here, right.

So that is what you have out here, right. So I think we have something like CH3, right, COOH, let us say, right. That is what we have here. And from there, we see that we get 1 CH4 and then CO2, let us say, right. 1 more oxidized and 1 more reduced form of the relevant carbon, let us say, right. Again that is fermentation. So in respiration though you have different electron acceptors and donors, right.

And then you have the relevant redox process going through, let us say, right. So again why is this or why are we looking at methane production? Typically, methane production, the conditions that promote methane production, let us say, typically would be favourable for dechlorination of, what do we say, the chlorinated solvents, let us say, right.

So if you see that you have methane in the particular system, let us say, then you can say, let us say, or that is one of the indicators that helps you decide, let us say, is the particular system good enough for or to bioremediation of chlorinated solvents which are pretty toxic compounds, let us say, right. So that is something to keep in mind.

Again what have we discussed? Initially aerobic case where we end up having electron acceptor and electron donor, one of which can be your contaminated compound releasing CO2 and H2 and so on, let us say, right or even H20, let us say, right depending upon the type of reaction. And then some of these particular reactions, let us say, you are going to have hydrogen released. As in hydrogen release, why is that important?

Some microbes will only promote, what do we say, reactions where hydrogen acts as the reducing agent, let us say, right. So in that context, you need to form or have this hydrogen release compounds or such that is something to keep in mind too. And in that context, we looked

at electron acceptor being oxygen and then the anaerobic cases. So we looked at aerobic and anaerobic cases, let us say, right.

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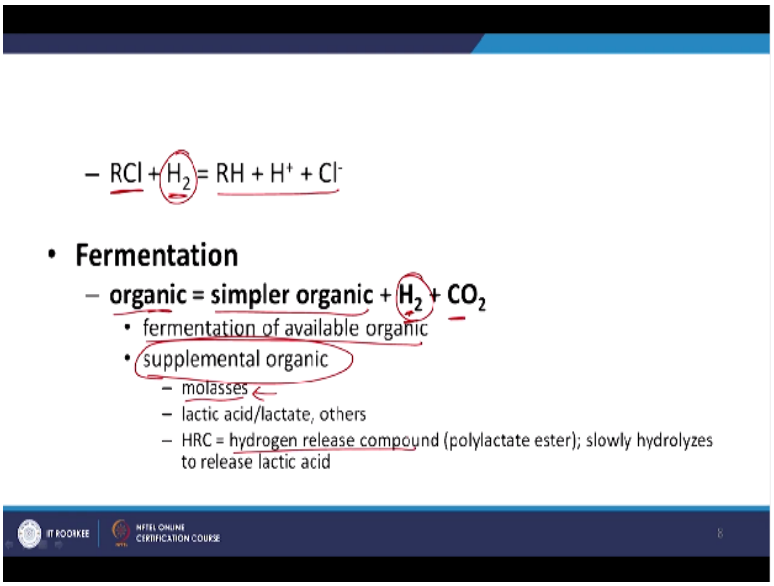

So let us move on. So again as we mentioned, another electron acceptor is the chlorinated solvent in the presence of hydrogen, let us say, and these are the relevant dechlorination steps, let us say, that can occur. I think one of the examples that we have looked at repeatedly is PCE going to TCE going to 1,2 DCE, vinyl chloride and so on. As you see, it is more or less typically dechlorination in one way or the other, let us say, right.

And again some microbes are very preferential to, what do we say, having hydrogen as the reducing compound here, right. So let us move on. So fermentation as we briefly discussed here, we have one particular organic compound that goes to a more simpler organic compound H2 and CO2 depending upon the type of, what do we say, compound out here. So fermentation of available organic itself can go through or you are going to add that particular organic that can undergo fermentation.

Why is that? Because maybe sometimes you want to have formation of your H2, let us say, right. So let us go forth. So typically that is molasses that is added quite often, let us say. So molasses can act as your electron donor or can undergo fermentation too. So that is something to keep in mind because we are going to look at this particular example later on or much down the line, let

us say, right.

Not down the line, I think we have a particular case study that we are going to look at where they introduced the molasses, right. So again either fermentation, let us say, or/and try to get the hydrogen or molasses itself acts as the electron, what do we say, donor here, let us say, right. But again typically though you are trying to promote formation of hydrogen. Again lactic acid and then or as I mentioned other hydrogen release compounds, let us say, right.

So I guess with that we are now going to move on to, let us say, looking at the relevant aspects for a case study where we have or where they looked at bioremediation, let us say, right. So let us look at what we have out here?

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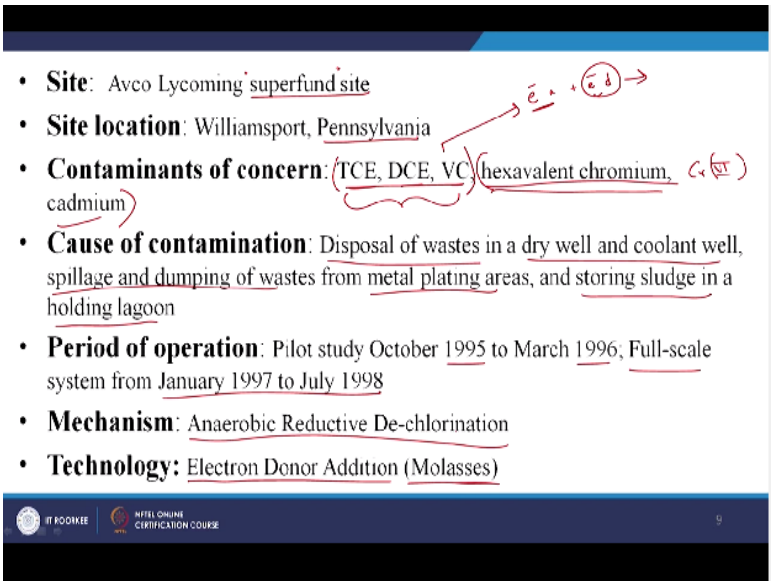

So we have a particular superfund site. Again superfund site as I mentioned is how they classify or refer to in the US anyway sites that are high, very high up the priority, let us say, right or are high priority, right. So that is what we have out here. And it is in Pennsylvania, okay. And then again TCE, DCE, VC and more importantly even hexavalent chromium, chromium in oxidation state VI and also cadmium, right.

And how did they end up, how did we end up or they end up contaminating the relevant site? So disposal of waste in a dry well and the coolant well, spillage and dumping of wastes from metal

plating areas that is why you have the relevant heavy metals. There are other heavy metals too but these were major concern because they were carcinogenic, let us say, right. Some of them are carcinogenic.

And also sludge was stored in a holding lagoon that too without proper lining or such. So some of it leached out into the relevant subsurface, let us say, right. So you have as you see a wide variety of contaminants. These are all chlorinate hydrophobic contaminants. Hexavalent chromium is very much hydrophilic. It is remarkably soluble, let us say. Cadmium is somewhat soluble, that is why to leave it in the present as a solid, right.

So it is a relatively complex system, let us say, right. So they were looking at, what is it now? The relevant aspect with respect to bioremediation, right. So they were looking at a pilot scale study initially from 1995 to 1996 for a few months, around 6 months. And then full scale from, for around 1-1/2 years, let us say, right. So that is what we have out here. And what are they looking at?

They were typically looking at anaerobic reductive dechlorination, let us say, right. Anaerobic reductive dechlorination, so obviously they were not pumping oxygen through and they were typically looking at these contaminants. And how is it they are looking at? Anaerobic dechlorination, right. So let us look at what we have out here, right? So electron donor addition. So they say they are adding electron donor here, right.

So it can be 2 ways, let us say. Molasses itself can act as electron donor or typically, let us say, you can have maybe fermentation, let us say, and have hydrogen being released and that acting as an electron donor too. As you can see, all these compounds are chlorinated solvents, right or chlorinated organics. That means the carbon there is oxidized form or it can act as an electron acceptor.

So what do you need or what is the solution lacking? It is lacking an electron donor, right. As you know, you need an electron acceptor and an electron donor for the redox process to go through. You already have the electron acceptor. So you need to add an electron donor, right. And

they are trying to add it in the form of molasses, let us say, right. So that is the relevant approach out here, right. So let us look at some of the background out here.

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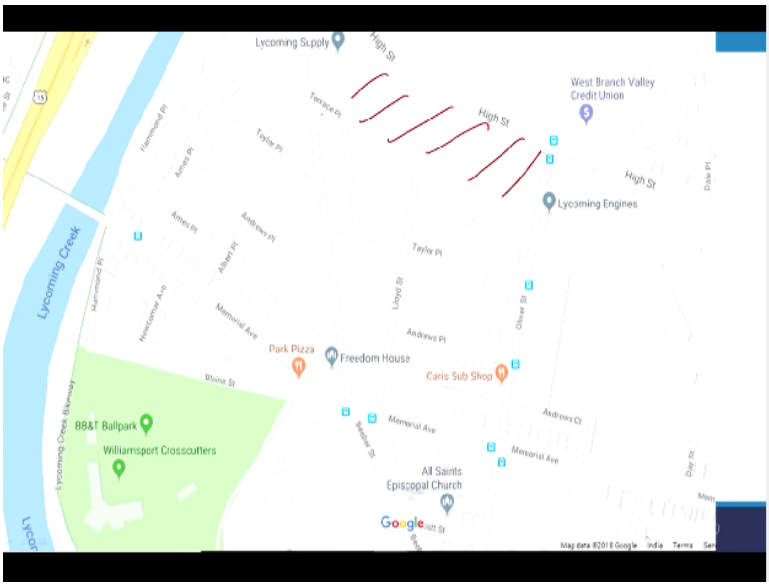

So as you see again within a well built up area, I believe this is where the site is, right. So let us look at what we have out here. Again as is usual very well populated or and in what do we say, high commercial zone and so on and also surface waters nearby, right.

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And I believe now they are using it as a parking lot as you can see out here and the recent Google map based picture, right. So earlier or as you will see soon, it was sandwiched between the high street and the Oliver street, I guess, right.

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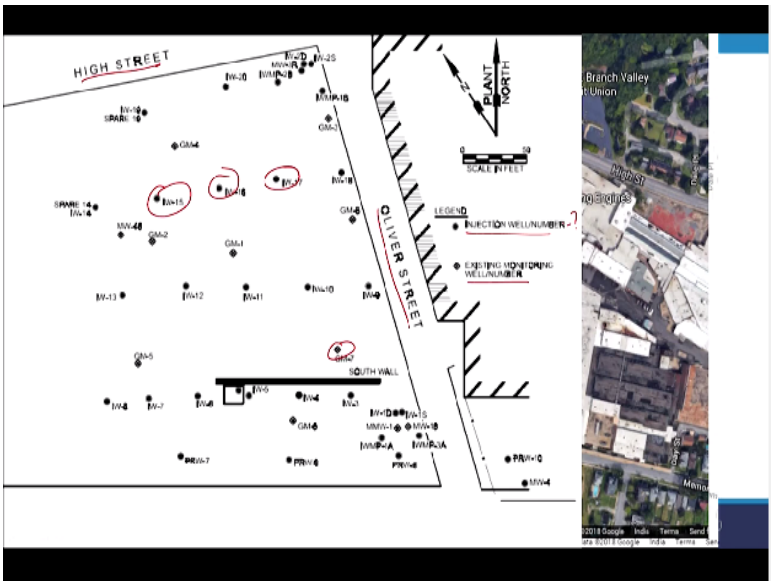

So let us look at what we have. So this is the relevant site. This is the high street and this is the Oliver street, let us say, and right. And as you can see, we have different injection wells and also existing monitoring wells, right. Number of injection wells within that particular site and some existing monitoring wells, right somewhere out here, right. So that is something to keep in mind as in depending upon the site heterogeneity, you are going to obviously want to have multiple injection wells and so on and so forth.

What are these injection wells for? We are trying to add the electron donor, let us say, or the compound that can act as the electron donor, let us say, right. And what are we adding? It is molasses in this case, let us say, right. So that is something to keep in mind. Again I believe that is a by-product of sugarcane processing and so on and so forth now, right. So let us move forth, right.

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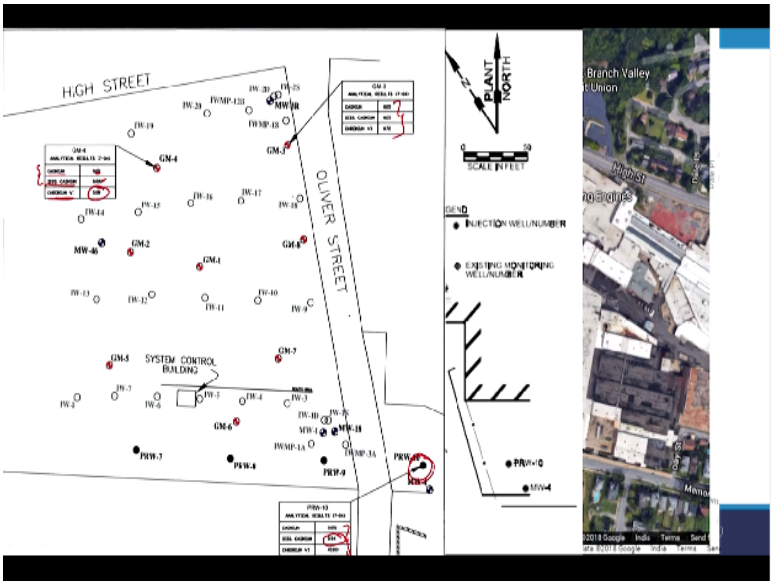

Again more or less better picture but here we have an idea about the relevant concentrations, cadmium, right. Typically, these are in ppm. So cadmium here they were looking at 2 aspects. (()) (26:16) cadmium or cadmium and the relevant solid phase and also the one in the dissolved cadmium I guess. Both are relatively high. And again chromium VI typically only dissolve and that is what you see out here.

So again similar ranges at different particular wells but off the site. As you can see, there are relatively less but dissolved cadmium for same reason is still relatively high, let us say. But this as you can see is slightly off the major zones of contamination, let us say, right. Again different aspects. So again we do not have complete picture here.

That is obviously because we do not have enough data available in the public domain though, right. So preferentially in this case, we would wanted to have contours of the relevant contamination, let us say, or contaminants and so on and so forth. So we get a clear idea about the relevant picture, ground water flow direction, let us say, velocities and so on and so forth. But we could not find that level of data here, right. So let us look at some of the data.

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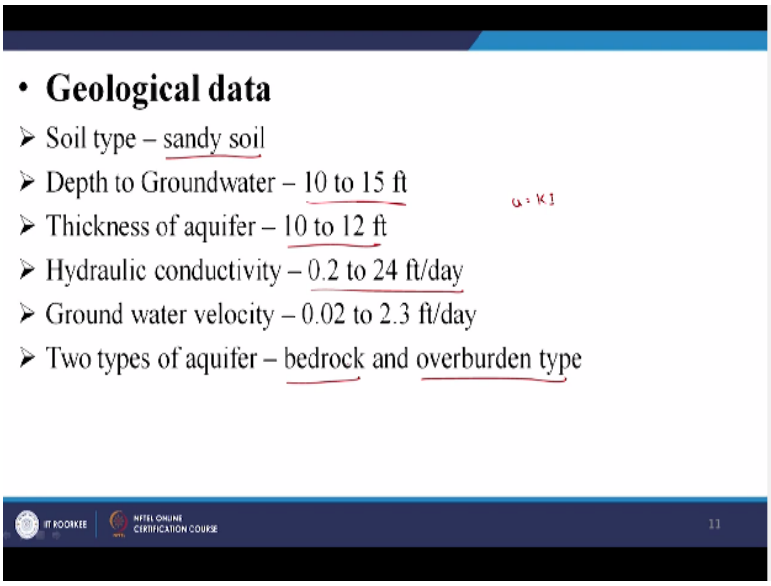

So soil type, sandy soil, okay, hydraulic conductivity is relatively high. Depth to ground water is 10 to 15. So that means typically shallow aquifer. Again thickness of aquifer 10 to 12 feet. Conductivity I guess varies considerably, right. Ground water velocity, thus obviously will vary, right. You know that Darcy's velocity=Ki, right. And types of aquifer, one the, what do we say now, one open and one the confined aquifer, let us say, right. Unconfined and confined aquifers, right.

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Chemicals	Concentration of contaminant(ug/l) prior to any treatment
TCE	700
Hexavalent chromium	3000
cadmium	800

ROD Clean-up Levels

Chemicals	Concentration of contaminant(ug/l)
1,2 - dichloroethene	70
Cadmium	3
Chromium VI	32
Trichloroethene	5
Vinyl chloride	2
Manganese	50

So contaminant information, right here we just have a snapshot. There are other contaminants too. But some of the major contaminants were TCE, right, chlorinated solvent; hexavalent chromium; and cadmium, let us say. As you can see there are remarkably high concentrations or

these are very high concentrations.

And ROD is record of decision as in once the relevant people analyzes the site and then talk to the relevant administrators, the public and so on and so forth. In the US, they more or less set up these clean up level goals, let us say, right. And what do they want to degraded to, let us say. For TCE, they want to bring it down to 5 from 700. For hexavalent chromium, they want to bring it down to 32 from 3000. So almost decreased by 100 times, let us say, right.

And then cadmium, they want to bring it down from 800 to 3, let us say. Again more than 100 or 500 times decreased, let us say, is required. As you can see, the levels that they need to be cleaned up to are remarkably less compared to the current levels of contamination before bioremediation, let us say, right.

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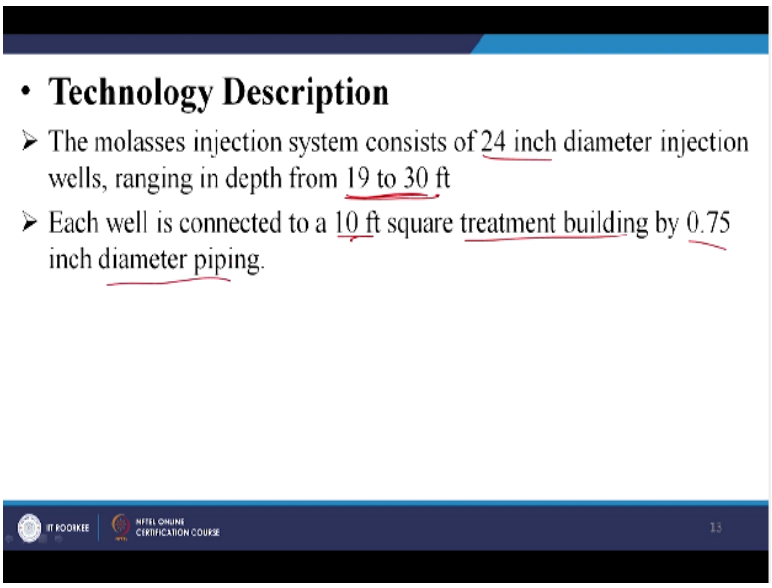

So let us look at what they have? So they were looking at injection systems length through 24 inch diameter wells and again different depths. And again they were getting this molasses from, let us say, a particular building, right through relevant piping and so on, right.

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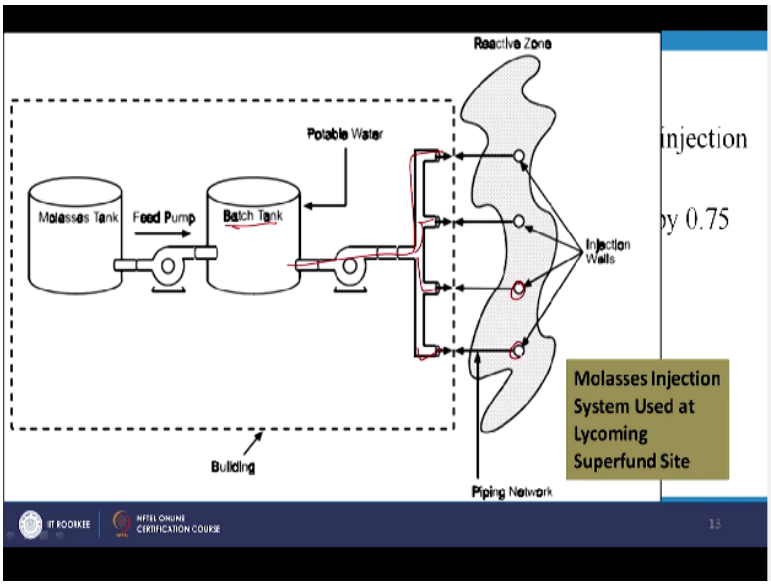

So we have portable water that is used to dilute molasses in this particular batch reactor, right. And then that is pumped to various particular locations, right. This is the top view obviously, right. And they are then introduced in the relevant electron donor, let us say, which is molasses, let us say, right. And again that is what we have out here.

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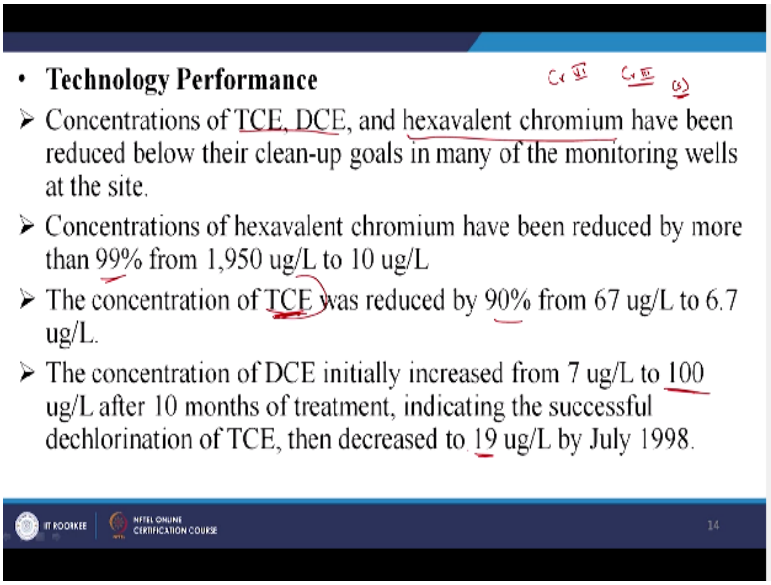

So let us look at the relevant performance. So typically looks like concentration of TCE, DCE, and hexavalent chromium have been reduced below their clean-up goals in many of the monitoring wells, right. Again how can hexavalent chromium also have been decreased, let us say. Chromium VI, it is oxidized state, right. So if I add reducing conditions or create reducing conditions, it can be reduced to chromium III, let us say, right.

Chromium III is insoluble and so it will precipitate out as particular solid typically, right. So that is something to keep in mind, right. And concentrations of hexavalent chromium have been reduced by more than 99%, right, we just looked at that. TCE around 90%, right. And concentration of DCE initially increased, right. And why is that? Because DCE is one of the by-products of TCE degradation.

And after that again, it further decreased to a particular value, let us say, right. So what is happening now? There are different electron, what is it now, donors out there. What are they? Hexavalent chromium, TCE and so on and so forth. So initially, let us say, you are going to have the microbes degrading those compounds that they find favourable to, right or from where they can or from whom they can gain more energy, let us say, right. Or the kinetics might be important too.

So initially, let us say, 1,2 DCE was higher because PCE or TCE was being degraded to 1,2 DCE. So once no more PCE or TCE is present, then the microbes are going to degrade this 1,2 DCE further. And that is what you see out here, right.

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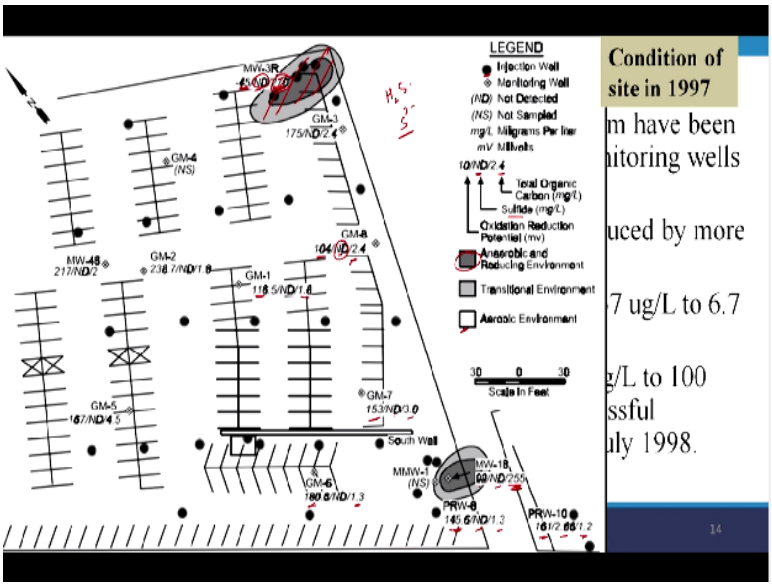

So let us move on and this is what you see out here. So before the relevant injection of the relevant molasses, let us say. This is the relevant scenario. Let us look at what we have? So we

have different injection wells and so on, right, monitoring wells and so on. So you have TOC values here, right, total organic carbon values at different sites, TOC. And this is the oxidation reduction potential, ORP, right.

So different ORP readings out here, right. And what else do we have here? Sulfide concentrations, let us say. Sulfide is not detected. So that means as we can see typically, let us say, sulfide will be present in reducing conditions, let us say, or when reducing conditions prevail, right. Typically, they are looking at H2S or S2-. So this is reduced compound. So as you can see, it is typically not detected, let us say, right.

And also ORP readings are other than at this site, they are typically positive and relatively high enough. So that means its oxidizing conditions are prevailing, right. And as you can see from this particular graph 2, only at a few locations, is it anaerobic conditions, right. And at most of the locations, it is aerobic conditions, right. And that is why have relatively higher, what is it now, ORP values.

So obviously for this particular well, I guess it is near this particular contaminated area may be and that is the reason why you have relatively reducing conditions and so on and so forth here, right. Again or maybe it is just the heterogeneity in the system, let us say, right. So that is something to keep in mind, right. So let us see TOC values, right. Are varying based on the contaminated site levels. Typically let us say, they are around 1 or 3 and so on, let us say, right. So that is something to keep in mind.

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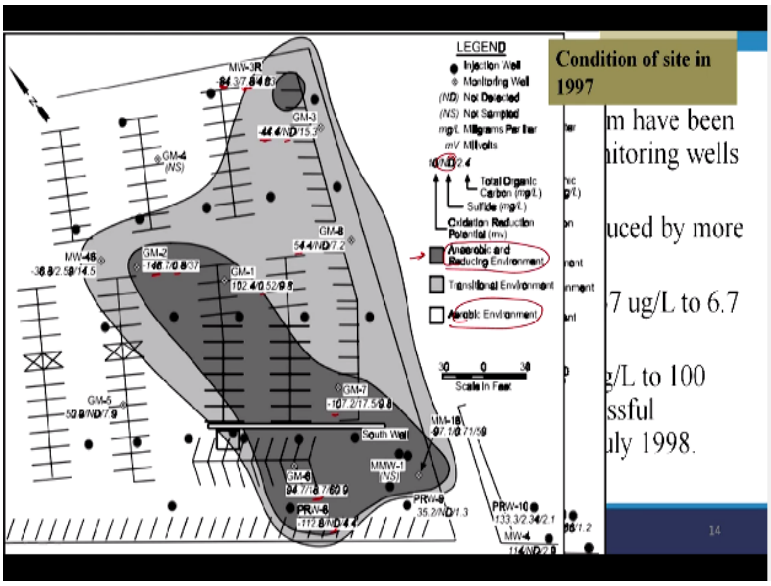

So after injection of the relevant molasses, you see now that the system has changed considerably now, right. So now you see that most of the cases, the ORP is relatively less, let us say, or reducing conditions prevail. And also the sulfide reading, right, is either still not detected or considerable in quite a few cases, let us say, right. You have reducing conditions at quite a few locations now, right.

And also obviously TOC2 will increase, let us say, because you are adding molasses, let us say, right. So that is what you see here. The picture obviously decreases, not decreases, changes to a more anaerobic condition. Earlier it was mostly aerobic and now you are adding molasses, let us say, which is an electron donor. So oxygen which was present earlier which is an electron acceptor, let us say, was consumed.

So now you have anaerobic conditions, right. Oxygen was present earlier, you are adding an electron donor and so that is going to reduce your particular oxygen and that is consumed. And now you are going to have more reducing conditions out here, right. So let us look at some of the data here.

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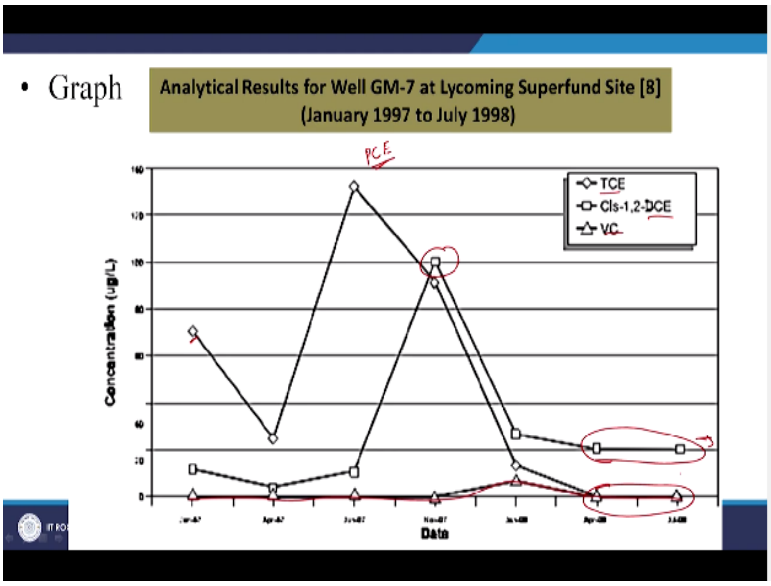

So as you can see here, TCE and DCE and VC. Let us look at TCE, I guess, right. So I guess the concentrations were relatively, okay. These are the TCE concentrations. More or less with time, you have relevant degradation. So there are some spikes, maybe PCE was present or there was desorption or such. There were some such reasons. So 1,2 DCE2, initially some increase as you can see and then decrease, right.

So I guess, this was the vinyl chloride case earlier. This is the vinyl chloride and this is the 1,2 DCE, right. And, not vinyl chloride, TCE pardon me. And same case with VC though. The VC degradation as you would have seen in the case of PRB, let us say, the VC degradation is relatively fast, let us say, right. I believe that was the case in that PRB case. And that is what you see here, let us say. So it is not rate limiting step or such. That is something to keep in mind, let us say, right. I guess I will end today's session with that particular aspect and thank you.