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# Lecture-35 Redox Chemistry of Soils-Continued

Welcome friends to this fifth and last lecture of week 7 of this NPTEL online certification course of environmental soil chemistry and in this week we are talking about the redox chemistry of soils.

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And in the previous 4 lectures we have talked about some, you know, we have talked about the basic overview of redox reaction as well as what is redox potential and we have also talked about the relationship of redox potential as well as pH, we have talked about the pe relationship, remember pe is basically the negative logarithm of electron concentration, almost it is an intensity factors just like the pH as well as redox potential.

And the pe sometimes used interchangeably with Eh for denoting the submerged condition and as well as the oxidation reduction potential of the soils. Oxidation reactions are mainly useful for different chemistry applications. However, reduction reactions are basically used for different soil applications. We have talked about the stability relationship, stability line of different oxidized and reduced ion pairs. And we have talked about what is the cut-off line and which are the minerals which are more, which tend more towards oxidation and which are the ion pairs which basically shows the tendency towards getting reduced and or remaining in the reduced condition. Then we have talked about the classification of submerged soils, we have talked about the paddy soils, we have talked about subaquatic soil, marsh soils.

And we have discussed their characteristics also, side by side we have also discussed about the implication of soil redox potential. Now, we started, you know, discussing about the characteristics of the submerged soils and we have discussed some important points now, today, we will going to start about discussing about these sequential reduction. Now, you know that the sequence of the reduction as you can see in this slide that the sequence of the reduction of various compounds in soil usually occurs in the order of oxygen, nitrogen, manganese, iron, sulphur.

So, always oxygen goes reduced oxygen reduced first followed by nitrogen. Then manganese, then iron, then sulphur and basically it is concurrent. And this order is basically concurrent with decreasing pe levels. So, if you see the pe levels, obviously, the pe will be highest in case of oxygen followed by nitrogen and then manganese and then iron and sulphur and so on and so forth. Remember that at pH at pe value of greater than 7, oxygen is reduced to, to form the H 2 O and with a decrease in the pe value.

This is followed by reduction of nitrate to nitrite and so on. We will see that in the next slide. And also remember that reduction of MnO 2 or manganese manganese dioxide is reported to occur at the same pe level as that of nitrate reduction. We will also see that in the next slide. And then comes the reduction of a FeOOH and to ferrous Fe 2 + and when sufficiently low pe levels have been attained, then we can see the reduction of sulphate ions and carbon dioxide.

So, these are the last couple of ions or compounds which are which get reduced when there is a decreasing pe or redox potential. So, we will see that in the next slide. (Refer Slide Time: 04:33)



So, in the next slide this is showing the sequential reduction obviously, you can see oxygen is first getting reduced to elemental hydrogen here and basically it should be 2H 2 O, it is not it should be 2H 2 O. Now, then second, the nitrate get reduced to nitrite which is very transient, but it is a reduced species nitrite and also you can see that manganese dioxide getting reduced to manganous Mn 2 + plus and followed by this FeOH whole 3 to ferrous.

So, ferric hydroxide to ferrous and then so on so forth you can see sulphate get reduced to sulphite and also other compound like carbon dioxide, phosphoric acids are getting reduced to their reduced counterparts. So, basically all these reduction reactions are, are following the reduction in their corresponding redox potential you can see here, in case of oxygen redox potential is + 830 millivolt. So, obviously, that shows high tenacity of oxygen to get reduced to water.

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So, let us move ahead and see you know what are the major electrochemical changes we can see when the soil is submerged. So, there are couple of major electrochemical changes. First of all, you will see a decrease in redox potential. It is very common when you submerge a soil, when you saturate the soil with water. And secondly, you will see an increase in pH in acid soil we have discussed this in the last class, in the last lecture.

And also a decrease in pH of alkaline soil, pH of alkaline solvent. So, basically you will see whatever their pH is whether it is alkaline or acidic, the pH tends to converge to the neutral condition, that is a pH of 7, then you will see the changes in specific conductance in ionic strength basically after the submergence, you will see an increase in specific conductance and then you will see drastic shift in mineral equilibria obviously.

There will be drastic shift in mineral equilibria because of redox reactions and then cation and anion exchange reactions will also influenced by these electrochemical, you know, by these submerged, by these submerge condition and also you will see the sorption and desorption of ions will also vary depending on these chemical changes in the submerged soils.

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So, let us see details what are the different types of conversion you know happens in case of different major nutrients major elements which are present in the soil. So, let us first start with nitrogen system or nitrogen transformation in submerged soils. So, this picture basically shows some you know a good nitrogen dynamics in submerged rice soil you can see here that this is the right route.

So, obviously, this is the water surface followed by this thin aerobic layer and then followed by this anaerobic soil. So, one thing is clear that these ammonium ions, which you can see here is getting you know is diffusing away to the, to the plant root. So, basically in the aerobic zone, in aerobic zone when we are applying different urea or ammonium fertilizers, these ammonium get converted to nitrate to the process of nitrification since it is an aerobic layer.

And also the nitrate get you know fixed by different atmospheric fixation. So, and this ammonium also get lost due to the formation of ammonia through volatilisation process as you can see here. So, when you apply the urea nitrate ammonium fertilizers, it is get either nitrified to nitrate or either get volatilized to ammonia. Then this nitrate goes you know downward showing a, through a diffusion process.

And this nitrate you know either leached away from the soil or it is getting denitrified through denitrifying bacterias to produce the reduced form of nitrogen that is either nitrous oxide or elemental nitrogen and this elemental nitrogen and nitrous oxides are released into the atmosphere. Also you know this nitrogen from the atmosphere get fixed through the biological nitrogen fixation.

And also due to the addition of organic manures and crop residues, the organic nitrogen will form. So, biological nitrogen fixation will produce the organic nitrogen. And also manures addition of manures and crop residues also produce organic nitrogen, this organic nitrogen through the process of mineralization produce the ammonium, this ammonium get fixed into the 2 is to 1 type of clay mineral or they can further be immobilized into the organic forms.

So, this ammonium get either fixed or immobilized in the organic form. Now this ammonium can diffuse away to the root zone of the rice plant. So, that they can take up this ammonium as a source of nitrogen. Also this ammonium shows upward diffusion into the aerobic layer and this aerobic layer further, in the aerobic layer it further undergoes the nitrification. So, this picture basically shows a very good illustration of the nitrogen dynamics in case of submerged soils.

So, mineralization of nitrogen is basically restricted to ammonification states obviously, it cannot in the anaerobic layer the mineralization of nitrogen stopped into this you know ammonium formation it cannot go beyond that, because there is no oxygen and also ammonification of organic matter also proceed to a very lower rate because of devoid of, this is, the surrounding is or the environment is devoid of oxygen.

And also intermediate products of decomposition forms in this anaerobic layer. So, this is basically in short that the nitrogen dynamics in the submerged soil.

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So, let us consider phosphorus dynamics in submerged soil. The mobility of phosphorus is higher, you know in submerged soil because of diffusion process get increased and then the phosphorus mobility of, phosphorus mobility is restricted to the top 30 centimeter layer of the soil even in submerged condition. Remember that the phosphorus fixation is more in the form of chemisorption you know on the colloids.

So, the fixation is more, but at the same time, when there is a fixation, the colloid fractions of phosphorus also get mineralized releasing or increasing its availability obviously, when the colloid fractions of phosphorus get mineralized it results in more availability because it converts into the more available and more soluble forms. And also remember that the solubility of phosphorus compounds get increased due to the presence of carbon dioxide and decrease in Eh.

So, hydrolysis of phosphorous compounds and its solubility will be more leading to higher solution of phosphorous. So, as a result of that, and also the mineralization of organic P will be higher. So, as a result of all these you know, processes the phosphorus availability in submerged soil is relatively higher than that of you know, oxic soil or in case of aerobic soil. So, in case of submerged soil the phosphorus availability generally increases.

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Now, let us talk about the potassium in submerged soils. Now, it increases generally the potassium availability increases due to the presence of a ferrous ion, which and also this potassium get released from micas in the submerged soils. So, their availability increases some time the availability of applied potassium decreases due to the formation of some sparingly soluble iron potassium complexes.

So, one you know mostly the potassium availability in the submerged soil increases. However, in some cases where there is a formation of sparingly soluble iron potassium complexes, then the applied availability of applied potassium decreases.

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Now, if we talk about the sulphur in the submerged soils the sulphate which is an, you know oxidized form of sulphur reduce to its, reduce from that is hydrogen sulphide and then in the

extreme condition, it reduced to iron sulphide. So, it has basically when it reduced from sulphate to H 2 S and then to FeS it has basically 3 implication. First of all, sulphur supplied may become you know, you know insufficient okay.

Because, you know, in case of plants available form of sulphur is sulphate. However, the sulphate is getting reduced to the sulphide form, then zinc and copper may be immobilized in the form of zinc sulphide or, you know, copper sulphide. And then the H 2 S toxicity or hydrogen sulphide toxicity may arise in soil which is low in iron. So, when this soil is low in iron, the iron sulphide will not form, the hydrogen sulphide will form.

And as a result of hydrogen sulphide, you will see the sulphur toxicity as you can see in this you know, roots of the, roots of the rice plants. So this, this is because of the hydrogen sulphide toxicity okay.

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So, let us talk about the manganese in submerged soil. Now in case of aerobic condition you know the manganese dioxide is present and when it is getting reduced in the submerge condition due to the reduction, due to the reduction of redox potential, it converts to the Mn2+ form and then also water. Now, this Mn2+ is water soluble and available to the plant and the above this reaction is basically occurs almost coincident with the disappearance of molecular oxygen and nitrate nitrogen resulting in formation of manganese compounds.

So, when the oxygen get reduced, oxygen get depleted due to the, due to the submerge condition and nitrate nitrogen getting utilized by the microbes which are present in the anaerobic condition or facultative anaerobes then, what happens this manganese oxide you know MnO 2 or this manganese dioxide basically convert to manganous compounds that is Mn2+. Now water soluble and exchangeable ion increases on submergence and ensures a better supply of manganese in a flooded soil to rice. So, in case of flooded condition, the availability of manganese increases.

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Now we will talk about the iron in submerged soils. Now in the iron submerged soils basically in waterlogged condition ferric is reduced to ferrous we have already discussed that with concomitant increase in iron solubility by anaerobic bacteria, which uses iron oxides as electron acceptor in respiratory chain or terminal you know electron you know terminal electron acceptor in the respiratory chain.

So, basically the iron or ferric 3 reduced to Fe 2+ plus by anaerobic bacteria and it produces toxic effects. When the iron get increased, the toxic effect of plant can be seen which we call bronzing, bronzing disease as you can see in this picture, it is showing the bronzing of the rice plants. Now under anaerobic condition, owing to the reducing process hydrous iron oxide give rise to Fe 2+ according to the following equation.

As you can see FeOH whole 3 when it is getting reduced by accepting 3 protons and electrons it is reduced to Fe 2+ and producing 3 molecule of water. So, this is how the iron get reduced into the submerge condition and producing the iron toxicity.

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Now, let us talk about the zinc in submerged soil. Now, zinc deficiency in flooded soil thought to be related to high pH or the presence of calcium carbonate. However, zinc deficiency also occurs in acid soils. Now, when the soil is submerged, the concentration of many nutrients increases but not zinc. So, you can see when we are submerging the soil the concentration of phosphorous, available phosphorus increases.

Available iron increases, available manganese increases. However, in case of zinc it is not, we cannot see this thing. Now in acid soil, zinc deficiency may be attributed to the increase in pH under reducing conditions subsequent precipitation of franklinite or sphalerite. Now, decreasing the pH in submerged calcareous would usually increase in solubility. However, higher the soil pH, poorer the aeration and greater the zinc deficiency.

So, you can see both in highly alkaline soil as well as in acid soil zinc deficiency occurs as a result of submergence.

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Now, the next thing we are going to talk about is the redox reactions involving different inorganic and organic pollutants. Now, you see that manganese with the oxidation number of 3 and 4, then ferric, then cobalt with oxidation number of 3, then lead 4, all these oxides and hydroxides are thermodynamically stable in oxygenated system at neutral pH.

So, in case of aerobic condition, they are thermodynamically stable. However under anoxic condition or submerged condition, when you submerge the soil with water, reductive dissolution, a new process called reductive dissolution of these oxides and hydroxides occur and this reductive dissolution of these hydroxides and oxides occur through the, through some agents and these agents are, you know, either could be inorganic or it could be organic.

Now, here I have shown here 2 examples. You know here you can see the reduction of MnOOH and MnO 2 how it happens. So, you can see here this Mn(III) OOH which is a solid when it is getting reduced it produce the Mn 2+ okay and when this Mn IV, I mean IV O2 basically Mn O 2 get reduced it is produce the Mn 2+. Now, you can see in both these condition, the oxidation number gets reduced that means there are getting reduced.

So, changes in the oxidation state of the metal associated with the oxides above can greatly affect their solubility and mobility in soil and in the aqueous environment. How we will see and how this happens, we will see.

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The reductants can be either	inorganic or organic	
There are a number of natural good reducers of oxides and hy	and xenobiotic organic functional and xenobiotic organic functional and results and the second sec	groups that are
> Carboxyl		
> Carbonyl		
> Phenolic, and		
> Alcoholic functional groups o	f SOM	
Organic reductants	Inorganic reductants	
E.g., Microorganisms in soils and sediments	E.g., As(III), Cr(III), and Pu(III)	
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Now, these reductants can either as I have told you, the reductants can be either inorganic or organic in nature, okay. Now, there are a number of natural and xenobiotics organic functions with the xenobiotics means synthetic organic groups. So, natural or synthetic organic groups that are also good reducers of oxides and hydroxides and basically they include either carboxyl group, then carbonyl group, phenolic group and alcoholic function groups of soil organic matter.

So, you can see there are 2 types of reductants, one is organic reductants another is inorganic reductants. For example, in case of organic reductants you can see the microorganisms in the soils and sediments are one example of organic reductants. However, as far as the inorganic reductants are concerned you know, you will see arsenide, then chromium 3+ and then plutonium 3+.

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	$E^{\circ\hat{a}}\left(V\right)$	$E^{\prime\prime\prime}\left(V\right)$	
nafine (Bricker, 1965) /2 Mm(IV) O <sub>2</sub> (i) + 2H* + c = 1/2Mm <sup>2+</sup> + H <sub>2</sub> O	+1.29	+0.64	Reduction Half-Reactions along with standard reduction potentials (E <sup>*</sup> ) and reduction
nganite (Bricker, 1965) An(III) OOH(s) + 3H' + c' = Mn <sup>2+</sup> + 2H,O	+1.50	+0.61	potentials calculated under more realistic environmental
ethine (Rohie et al., 1978) jetIII) OOH(s) + 3H' + e' = Fe <sup>2+</sup> + 2H.O	40.67	-0.22	conditions (E°') at pH 7
nanite (Robie et al., 1978) /2Fe(III) O <sub>1</sub> (s) + 3H <sup>-</sup> + 6 = Fe <sup>2+</sup> + 3/2H <sub>2</sub> O	+0.66	-0.23	
gueine (Robie et al., 1978) /2Fe,(III) Fe(II) O <sub>4</sub> (s) + 4H' + ε = 3/2 Fe <sup>2s</sup> + 2H <sub>2</sub> O	+0.90	-0.23	
balt hydroxide oxide (crystalline) (Hem et al., 1985) CollID OOH(s) + 3H* + c' = Ca <sup>2+</sup> + 2H.O	+1.48	-0.23	

Now, let us see different redox reaction involving pollutants. So, in this table, in this table, you can see the reduction half reaction along with the, you know, along with the these reduction potential and also more realistic reduction potential, environmental condition reduction potential at pH 7. So, you can see it shows the reduction of Mn IV to Mn 2+, Mn III to Mn 2+, Fe III to Fe 2+, Fe 3 to Fe 2+. So, basically one is goethite. Another is hematite.

And then magnetite again Fe III to Fe 2+ and cobalt, cobalt III to cobalt 2+, we can see all these cases they are getting reduced okay. So, now, let us see let us extract some other information from this table. So, what are these?

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So, one thing is clear that oxidant strength decreases in the order of Mn IV III, Mn III or IV. So, you can see Mn III Mn IV okay and which is greater than this cobalt III oxides which is

further greater than Fe III oxides okay. Fe III oxides you can see these are the Fe III oxides okay. And this is basically the oxidant strength we can see based on these standard redox potential. So, you can see in case of Mn IV in both this condition, it is positive followed by this cobalt and then in case of iron it is already negative.

So, obviously, among all these fractions, the manganese Mn IV and Mn III will show the highest tenacity to get reduced followed by this cobalt and then followed by these Fe III, Fe III ions. Now, these iron oxides are more difficult to reduce than Mn III and Mn IV species obviously, since these Mn III and Mn IV are having positive. So, they are always easy to get reduced.

However, in case of this iron oxide, they are already having negative redox potential. So, their tenacity to get reduced is always low, thus Fe 2+ is easier to oxidize then Mn 2+ obviously, the species which is less tend to get reduced obviously will be tending towards getting oxidants because of obviously, as you can see, they have negative negative redox potential.



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Now, one other thing we can, another information we can see that the goethite and hematite could only oxidize oxalate and they are not strong enough oxidants to oxidize hydrogen sulphide, ascorbate or hydroquinone. So, since you can see they are already having the negative you know redox potential. So, they are always tends towards you know, their, their tenacity to get reduced is very low.

So, obviously, they can oxidize only oxalate. So, oxalate so, they are not strong. So, they are not strong enough oxidants to oxidize the hydrogen sulphide, ascorbate and as well as the hydroquinone. However at pH 4 the Fe 3+ oxide can oxidize all the reductants. So, this information we can gather from this table.

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	E° ′ (V)	$E^{\nu r \cdot d}(V)$	Reduction half-reactions along with standard reduction potentials (E*)
łydroquinone p-Benzoquinone + 2H* + 2e* = hydroquinone	0.699	0.196	and reduction potentials calculated under more realistic environmental
lscorbate Dehvdroascorbate + 2H' + 2€ = ascorbate	0.40	-0.103	conditions (E°') for several organic compounds
Hydrogen sulfide S <sup>1</sup> (s) + H' + e' = HS <sup>-</sup>	-0.062	-0.17	
Dualate 2HCO5 + 2H' + 2e' = -OOC-COO' + 2H2O	-0.18	-0.69	

And also you can see reduction half reaction along with the, you know, several organic compounds like hydroquinone, ascorbates, hydrogens, you know, and so ascorbate hydrogen sulphide, oxalates. So, as we have told that goethite and hematite could only oxide you know oxidize oxalate. So, oxalate have let us see what is the, what is the redox potential of oxalate. It is - 69 which is less than this hematite and goethite. So, obviously, it can further oxidize these oxalates but not the hydrogen sulphide, ascorbate and hydroquinone.

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So, what are the, what is the mechanism for reductive dissolution of metal oxides and hydroxides. Now, the reductive dissolution of metal oxides and hydroxides occur in 3 following steps. First step is diffusion of the reductant molecule to the oxide surface. Second step is surface chemical reaction after you reach to the, you know, oxide surface, it produced some reaction in the surface.

And then, third is release of reaction products and diffusion away from the oxide surface. So, you can see there are 3 processes. Now, among these 3 processes the first one and third one is transport steps obviously, one is getting at you know towards the reductant molecule going towards the oxide surface and then reaction products are diffusing away from the oxide surface.

However, the rate limiting step is a reductive dissolution of oxides appear to be surface chemical reaction of the second step. So, this is the rate limiting step. Now, let us see how it happens.



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Now, this reductive dissolution can be described by both inner sphere and outer sphere complex, we have already seen what is inner sphere complex and outer sphere complex in our previous lectures, okay. Now, this inner sphere complex and outer sphere complex based reductive dissolution can be you know can be expressed in terms of 3 mechanism. One is called precursor complex formation.

Second is electron transfer, second is electron transfer, and third one is called the breakdown of successor complex. Let us see in details.

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So, here you know the reductive dissolution can be described both in terms of inner and outer sphere complex, we have already discussed. Now inner and outer sphere precursor complex formation that is the first step or first mechanism, precursor complex formations are adsorption reactions that increase the density of the reductant molecules at the oxide surface which promotes electron transfer.

So, obviously, we know that the first step is the transfer process and when the reductant get attached to the oxide surface, will produce the you know precursor complex form, it forms a precursor complex and then promotes the electron transfer. In the inner sphere mechanism, the reductant enters into the inner coordination number sphere via ligand exchange and bonds directly to the metal centre prior to electron transfer.

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So, you can see this shows that these 3 mechanism in detail. So, first of all is the precursor complex formation you can see both in case of inner sphere complex and outer sphere complex. In the inner sphere complex there is M III H 2 O whole 6 3+ you can see it is you know one example is given by phenol. So, you can see the inner sphere complex is produced and then it is reduced.

So, this is a precursor complex and also in case of outer sphere complex, it is a precursor, it is a precursor complex and then the second step you know electron transfer is going on between these A and these. So, when the electron transfer happens between these metal as well as these, of these, these group A group of phenol. Then we can see that it reduced to Mn 2+ similarly, here you can see and in the third phase obviously, the breakdown of the successor complex.

So, you can see the successor complex for the breakdown to release these, release these A and then reducing, ultimately reducing the complex to M 2. So, basically in the 3 steps, in both inner sphere and outer sphere complex you can see the precursor complex formation is the first step. Second is electron transfer. You can see here from metal to the A group of the phenol and then breakdown of successor complex where it is further breaking down to produce the successor complex with a reduced compound which is having the oxidation number of 2 in case of metal. So, this is how the reductive dissolution basically occurs.

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Oxidation of inorganic pollutants, manganese oxide can oxidize a number of environmental important ions like chromium and plutonium you can see here this you know plutonium also. **(Refer Slide Time: 30:33)** 



Chromium, it is getting you know chromium III is quite stable and also you know it get oxidize, it is get oxidized to chromium VI which is very toxic and it is a carcinogenic. It is very carcinogenic and this oxidation is mediated through manganese.

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And also you know you can see the conversion of chromium III to chromium VI happens by you know most of these reaction basically oxidation occurs in the first hour at higher temperature there is a rapid oxidation rate followed by slower rate and the decrease in the rate of chromium III oxidation has been ascribed to a number of factors including the formation of surface you know precipitate that effectively inhibits further oxidation.

And also you can see that these manganese can oxidized the plutonium here you can see that if we plot the time and oxidized chromium formation obviously, you know as the temperature increases higher temperature, the rate also we can see the rapid oxidation okay. So, these are different types of oxidation mediated by inorganic manganese.

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Also similar in case of arsenic arsenite can be oxidized to arsenate which is As V.

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So, this arsenite can be converted to arsenate by a set of reactions and these reactions have been defined here and ultimately producing from arsenic with the III oxidation number to arsenic with the V oxidation number. And this reaction involve the formation of an adsorbed layer oxygen transfer occurs in the you know here this is an adsorbed layer and you can see the you know the oxygen transfer occurs and HAsO 2 which you can see HAsO 2 is oxidized to H 3 AsO 4. And ultimately this arsenite converted to arsenate.

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System	Time to oxidize 50%	Driving force at pH 4 \Deta (V) <sup>b</sup>	Source
$-MnO_2:As(III) \rightarrow As(V)$			
pH 4, 298 K, 14 m2 liter-1	10 min	+0.529	Scott and Morgan (1995)
$6-MnO_2$ : Se(IV) $\rightarrow$ Se(VI)			
pH 4, 308 K, 14 m2 liter-1	10 days		
pH 4, 298 K, 28 m2 liter-1	16 days	+0.092	
pH 4, 298 K, 14 m2 liter-1	30 days		
$-MnO_2$ : Cr(III) $\rightarrow$ Cr(VI)			
pH 4, 298 K, 71 m2 liter-1	95 days	+0.011	Eary and Rai (1987)

So, these reactions are inorganic redox reactions with manganese dioxides are given here, you can see ultimately summarily we can see arsenic III can be oxidized to arsenic V, selenium IV can be oxidized to selenium VI, then chromium III can be converted to

chromium VI and these are, these are the time to oxidize to 50% and this is the driving force you know, which is basically you know oxidizing this species.

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Now, this is the last slide obviously, it is basically you can see that, the redox reductive dissolution can not only occur through you know these oxidation not only occur through manganese oxide, which is an inorganic mineral and also in the reductive dissolution also of manganese oxides can be mediated by different organic pollutants also, we have seen that the reductive dissolution because phenol is attaching.

Remember the phenol is attaching and then it is reducing the Mn VI to Mn II. So, with substituted phenols, the rate of dissolution was proportional to substituted phenol concentration and the rate basically increase at pH decreases, as pH decrease and phenol containing different alkyl, alkoxy and other electron donating substituents you know, which are you know slowly degraded.

And para-nitrophenol reacted slowly with Mn III and Mn IV oxides and the increased rate of reductive dissolution at lower pH may be due to more protonation that enhance the creation of precursor complexes or increase the protonation of protonation level of the surface precursor complexes that increases the electron transfer rates.

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So, guys, you know we have, we have come to the last slide of our week 7. So, we have discussed in details about the different chemical dynamics of submerged soils and we have discussed in details about the redox chemistry of soils. Although there are some other points which is still need to be covered. However, if you are interested you should consult these books like environmental soil chemistry by DL Sparks.

You can also consult the nature and properties of soil by Nyle C. Brandy and Well and also you can consult these papers which is a one of the seminal paper chemistry of submerged soil by Ponnamperuma. And so, these will give you more enriched information about the nutrient and other elemental dynamics under the submerged condition. So let us wrap up this week and this module. Let us meet in our next week or next week of lectures and then we will start a new module. Thank you very much.