Environmental Remediation of Contaminated Sites
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Lecture - 53
Bioremediation: Part-1

Hello every one again, welcome back to latest lecture session. So we have been looking at, I believe a particular example in the context of a soil vapor extraction. So we were given what we say data with respect to let us say different grids and we had let us say the concentration of benzene in the gaseous space at around a particular depth at around 3 meters, Pardon me. And we looked at calculating or estimating the total mass, and in that context we assumed or presume that no NAPL is present.

And then we went ahead and looked at the relevant concentrations and then looked at calculating the total mass. I think we came up with around estimate with an estimate that you know one ton around one ton of the relevant benzene was present. So in that context, obviously you need to be able to design a system that almost all of this will be removed, especially through your soil vapor extraction.

As in let us say once you a pump out the initial gas that is contaminated. Again, there is going to be desorption from the soil, you know, change in phase from the compound or you know, change in phase of the compound which is absorbed onto the soil, into the gaseous phase. Same case for the compound that is in the aqueous phase it is going to change its phase from aqueous to gaseous. As in what is going to happen here?

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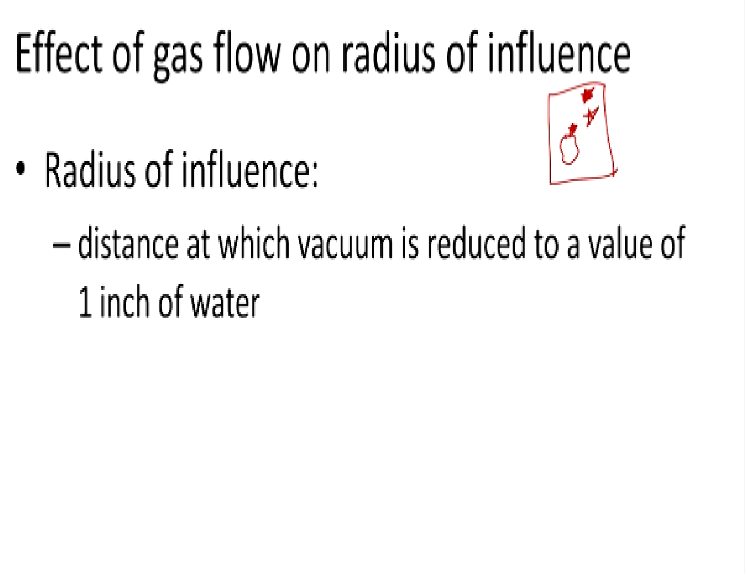

Effect of gas flow on radius of influence

- Radius of influence:
  - distance at which vacuum is reduced to a value of 1 inch of water

Let us see you have soil out here and you have the contaminant absorbed onto this particular soil. And let us say you have this particular contaminant in the gaseous phase. So what is going to happen ones you know I remove this particular gas. There is not going to be any more contaminant out here. So what is going to happen, again, then this particular contaminant is going to desorb or going to change its phase again, there is going to be equilibrium again.

The equilibrium has shifted because you removed the contaminated gas and thus again, you are going to end up with what we say equilibrium shifting and thus the driving force again, so we are going to have other equilibrium again or new equilibrium again. So that is something to keep in mind. So in that context, we are trying to look at effect of gas flow on the radius of influence and there are different ways to look at or define radius of influence, but for having a constant reference, we are going to look at one inch of water to be the threshold.

You know for calculating this radius of influence, so let us look at the data that we have out here, and let me go back to my excel sheet.

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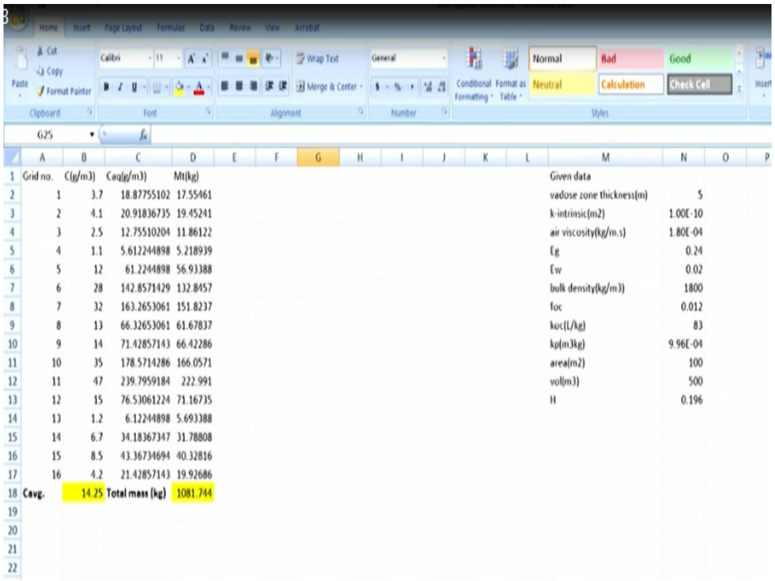

Grid no.	C(g/m3)	Caq(g/m3)	Mt(kg)
1	3.7	18.87755102	17.55461
2	4.1	20.91836735	19.45241
3	2.5	12.75510204	11.86122
4	1.1	5.612244898	5.218939
5	12	61.2244898	56.93388
6	28	142.8571429	132.8457
7	32	163.2653061	151.8237
8	13	66.32653061	61.67837
9	14	71.42857143	66.42286
10	35	178.5714286	166.0571
11	47	239.7959184	222.991
12	15	76.53061224	71.16735
13	1.2	6.12244898	5.693388
14	6.7	34.18367347	31.78808
15	8.5	43.36734694	40.32816
16	4.2	21.42857143	19.92686
Cavg.	14.25	**Total mass (kg)**	1081.744

Given data	
vadose zone thickness(m)	5
k-intrinsic(m2)	1.00E-10
air viscosity(kg/m.s)	1.80E-04
Eg	0.24
Ew	0.02
bulk density(kg/m3)	1800
foc	0.012
koc(L/kg)	83
kp(m3kg)	9.96E-04
area(m2)	100
vol(m3)	500
H	0.196

So I plotted the relevant data here.

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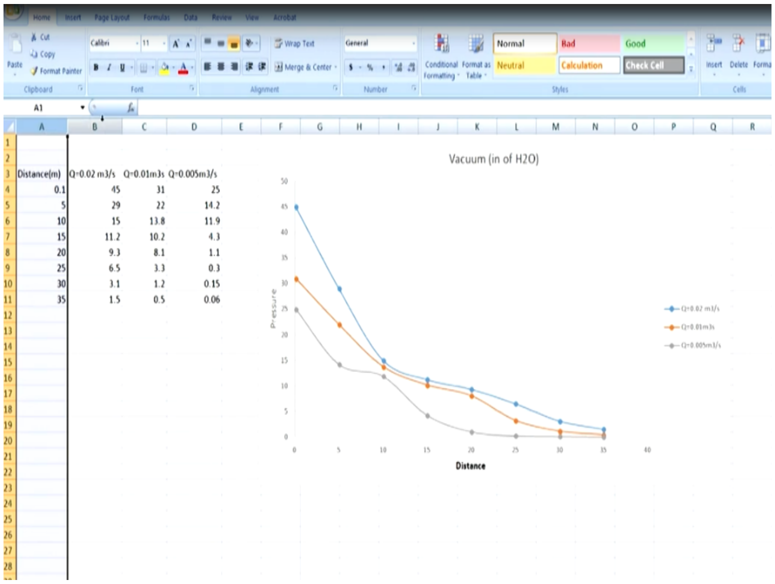

Distance(m)	Q=0.02 m3/s	Q=0.01m3s	Q=0.005m3/s
0.1	45	31	25
5	29	22	14.2
10	15	13.8	11.9
15	11.2	10.2	4.3
20	9.3	8.1	1.1
25	6.5	3.3	0.3
30	3.1	1.2	0.15
35	1.5	0.5	0.06

So in column A I have the distance, column B, C, D correspond to the pressure readings, let us say at different distances for different flow rates. And what are the flow rates here, 0.02,0.01 and 0.005 and then I plotted them here. So here on the x-axis we have distance 0 to 35, and on the y axis we have the relevant pressure here, so let us just try to understand the system. I mean obviously it is self explanatory, but just look at that, I guess. So closest to this particular center or the center of the well, right, which is pumping out the gas, you have the highest pressure.

And the highest pleasure is 45 inches of water and that should obviously be the case for the one, that is pumping out more gas per time. And that is what you see, It is corresponds 0.02 meters cube per second flow rate. And obviously as I move away from the particular well let us say you see that it is decreasing out here, as in the rate of the influence or the effect of this particular pumping the gas out decreases the farther away you are from the particular center line of the well, So that is what you see.

But obviously looking at this figure, let us say rather than just the table gives you an idea about, you know, the, maybe the complexity of the system as in it not linear as in just because it is 0.0 at 0.02, it is 45 out here does not mean at 0.01 it is going to be half of that as in it is not going to be 22.5 as we see it is 30 let us say for 0.01 and it is almost 25 for 0.005. So there are different aspects involved here, one aspect was the viscosity of air certainly that is something that we had data for, but it is not really required.

But you can use that to understand the system here, so obviously you need multiple data for multiple sets of data for different wells at different distances. Again, even with you know, distance let us say it is not as if it is linier now. If it is linear, you just have a straight line out from here to here. But you see that is not the case. There is a dropout here and then it is going to be more linear, so 2 or 3 different scenarios are playing out here. So it is certainly not linear, so that is the something to keep in mind.

And that the reason why one needs to go in for let us say a measurements at different or looking at different variables, like a flow rates and the distance here, So this is what we have out here, So here, what is it that we are looking at? We are looking at that particular, what we say, a flow rate, let us say, relevant to the, not particular flow rate, pardon me? The distance at which, let us say the pressure is at least one inch of water.

So let us look at that. So if the pressure is somewhere out here and one inch of water is somewhere out here, so we need to draw that particular case and look at it. So for this case it is around 20, this case has in 0.005 meter cube per second. The radius of influence will be around

20, for this one around this as in 0.01 meter cube per second and it is at around 30 and for this case at around 35.

But that is obviously, you know, we are visually estimating it, but we need to obviously interpolate it. Let us just try to do that I guess. So we will try to do that for one particular case, but I guess I need to switch from one data to the other. So I will just try to do it for one case, you know, 0.02 meter cube per second. I think we have the case for, let me look at the data here once. So this is it and a 35 it is 1.5 and at 30 it is 3.1.

So maybe, let me do it for this particular of case 0.01 obviously it can be used for both the cases, at 30 it is 1.2 and at 35 it 0.5 let me just write that, write that down at 30 its 1.2 and at 35 it is 0.5 and obviously I want to know, you know, what the case at what distance is it that I ended up with one inch of H2O. So at 30 so it obviously will be, the distance will be between 30 and 35 and let us try to calculate that.

So that is going to be 30, and what do I have here? The difference 30 +35-30 and the difference in pressure in that case is 0.5-1.2 * what do I need it further 1-1.2. And with that, I guess I can calculate the relevant radius off inference for the 0.01 same case, I can do that interpolate per 0.02 I need to extrapolate obesity but use the same scale there and more or less, go ahead and estimate my particular value here. And so this will be the radius of inference for Q=0.01 meter cube per second.

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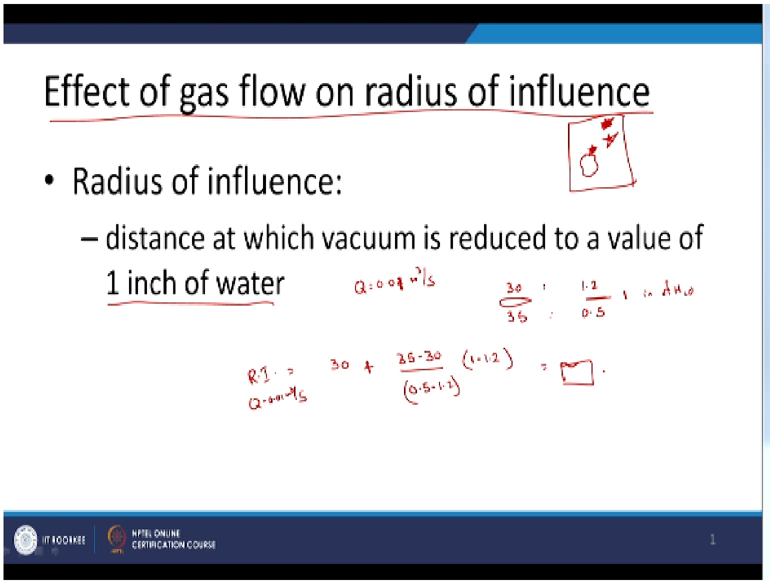

Effect of gas flow on radius of influence

- Radius of influence:
  - distance at which vacuum is reduced to a value of 1 inch of water

$Q = 0.01\ m^3/s$

$\frac{30}{35} : \frac{1.2}{0.5}$, 1 in H_2O

$R.I. = 30 + \frac{35-30}{(0.5-1.2)}(1-1.2) = \boxed{}$.

$Q = 0.01\ m^3/s$

And I believe I plotted that out here.

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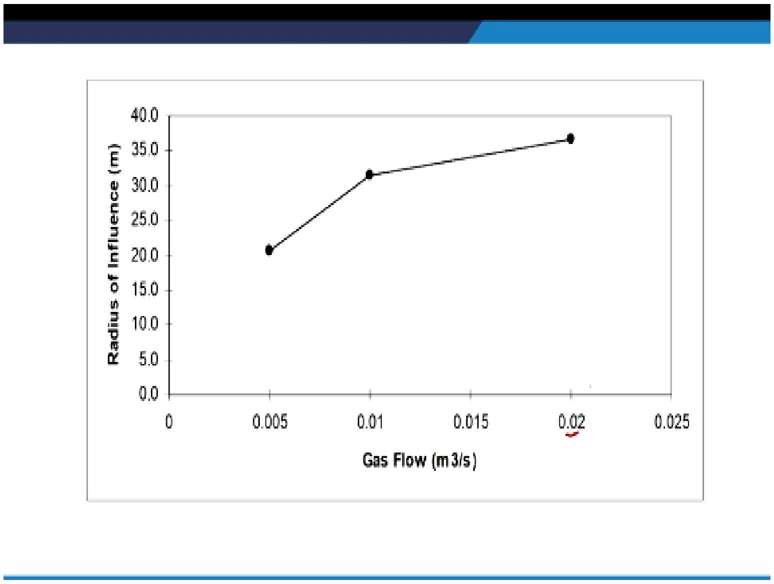

So as expected 0.02 will have the highest what do we say radius of influence that I think is their around 35 but should be slightly greater than 35 and 0.01 again, maybe 31 or something like that. And for 0.005 it is slightly greater than 20 again, this is from linear interpolation or extrapolation now, so from this I how, what do we say? Some based on just the limited data that I have. I have the relevant a effect of gas flow on the radius of influence of the relevant well, so that is what we see out here.

So from here, you know we are going to use this particular data again later on when we are going to look at the placement of well, so what do we have here? I think we are supposed to look at, you know, calculate, let us see what the placement or where do I place the well, and how many wells and so on it, so let us look at the grid that we have. I think we have as square, this is the top obviously, that is 40 meters/40 meters.

So let us say if I look at a circle that inscribes this particular square, I have this particular square and let us say this is the center of this particular well, let us see, and let me look at what I am going to have. So I can calculate this particular diameter or the radius in two ways, I know that this is 40 this is 40 and then get this accordingly. Let us see, and then calculate the radius or let us say, you know, I know that you know, this is 20.

And this case, this should also typically be 20 this is 20 this is 20 now I know this is 20,20 the angle is 45 degrees here and 90 here and 45,45 and 90 degrees. So the ratio of the relevant sites will be 1:1: root 2. So from that, let us say if these sites are and ratio of 20:20 then this has to be you route 2 times 20 root 2 is 1.414*20 that will be approximately equal to 28.28 meters. So what are we calculating here, we just calculated the radius that is required to be able to cover this entire area now.

So if we have a radius of influence approximately equal to this 28.28 meters, I can then, you know, cover this entire area. Let us look at where that comes out to be. So for 28.28 let us say, 25,26,27,28 or 29 it comes out to be some such value near or less than 0.01 meter cube per second. So I can choose a one well just one well with you know, this particular gas flow, I can obviously interpolate that again with this part of gas flow, and just place that in the center of the well, and the way that we are defining the radius of influence, how did we do that?

We defined it as that particular area, let us say, or the radius, let us say, which will see to it that the system has or exerts at least one inch of water pressure and that particular, what do we say area now, so from that context we saw that we need for a radius of 28 or 29 meters, we just need 0.009 meter cube per second now so to be on the conservative side or estimate or conservative estimate, we can to go with the 0.01 meter cube per second, and relatively higher radius of influence.

So let us say we are going to choose what now we are going to choose just one well, and I am going to choose what do we say such that it is going to be placed at the center of this particular circle that inscribes this grid. I am going to place it in such a way and the radius of influences is, what is it now approximately equal to I think 31 meters or so and as we have just looked at it, let us say you know it is going to completely encompass this particular area or obviously you can go for smaller wells, as in 0.05 or you know or such wells.

But obviously you are going to have some inefficiency or such, let us say with respect to the energy and so on because you are going to have multiple overlaps in such. So those I guess is a more economical a designers.

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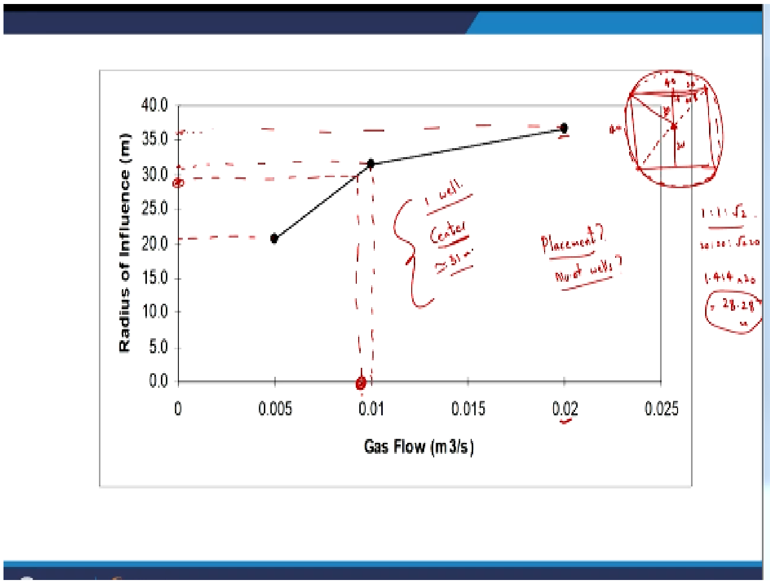

So now let us move on onto the next aspect. What are we supposed to look at is we are supposed to look at the estimate time to remediate the site, so how do we get that? Obviously we can look complex models let us say mass balance

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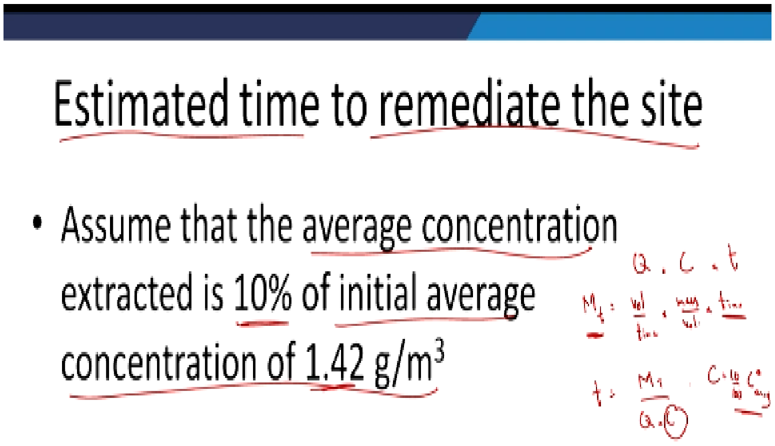

Estimated time to remediate the site

- Assume that the average concentration extracted is 10% of initial average concentration of 1.42 g/m³

$Q . C . t$

$M_t = \frac{vol}{time} . \frac{mass}{vol} . time$

$t = \frac{M_t}{Q . \boxed{C}}$

$C = \frac{10}{100} C^{0}_{avg}$

As in I can write dc/dt is equal to so on and so forth. And look at the time it takes to go to for the relevant concentration to reach zero, that is one way. Or I look at the simple case as in I will take the total mass, and then say that, the rate at which I am pumping out the mass will be given by Q, which is the flow rate that I just looked at times the average concentration let us say, and average concentration of pumping can be a assume to be some value.

So for that particular case, what am I doing here? I am obviously assuming that the average concentration extracted is 10% of initial average concentration of 1.42 gram per meter cube. So let us say we have, I guess initial average concentration is 1.42 of the gas, and I am assuming that only 10% of it is the average that I am pumping it out slightly conservative. But you know typical is required because the way you know a, as you reach the fag end of the system, you know this is going to be the case the rate again well.

How about we try going to measure this? We know that total mass is equal to what now a Q is volume per time, times concentration is mass per volume. And so here if I multiply it by this by time, then I will get the total mass, so to get the time it is nothing but total mass/Q. This is Q, this is c and this is t, total marks is Q*c*t. So time is equal to total mass/Q times c and the c is as we are seeing 10% of c0. C0 average. So that is what we have out here and we are going ahead with that particular case.

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$$t_r = \frac{M_t}{Q_{avg} C_{avg}}$$

Let us look at that calculation. So that is what we have out here are obviously.

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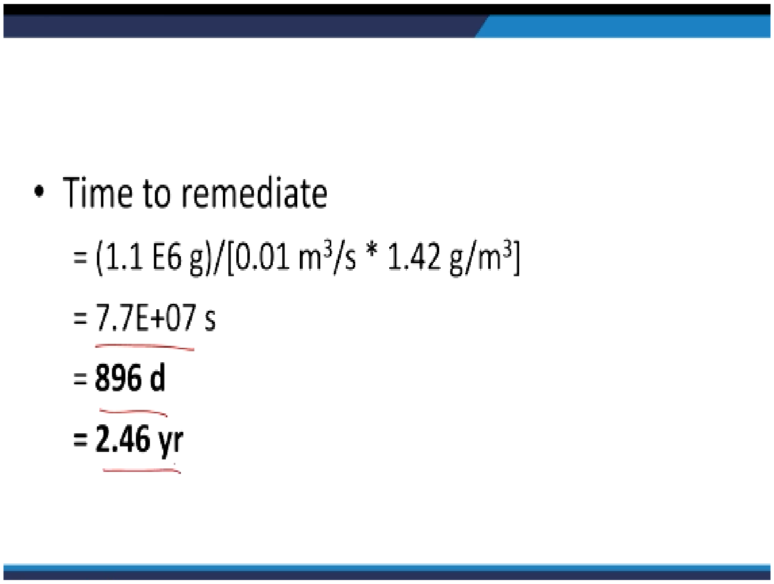

- Time to remediate

= (1.1 E6 g)/[0.01 m^3/s * 1.42 g/m^3]

= 7.7E+07 s

= **896 d**

= **2.46 yr**

And let us look at the calculations, so time to remediate it is 1.1*106 grams that something we calculated earlier, right in part A. This is the flow rate that we chose, so this is the total mass/Q times, the average concentration, and average 10% of that. Anyway, I believe the average we calculated was 14.2 grams per meter cube based on taking the average of all the relevant, what we say, a grids or the concentration in the relevant grids, and we now get this right and let us see what the value is turning out to be.

So we have these many seconds. Makes no sense to express it in terms of seconds. Even days do not seem something that is easy to understand. So in terms of years, we see that it takes almost two and a half years to if you rely only on soil vapor extraction to be able to pump out all the contaminant and how much contaminant almost equal to 1 ton of Benzene. Again, what are the aspects here involved that the benzene is not present only in the gaseous phase. It is also absorbed on the soil and also what do we say in the relevant water.

So obviously to pump out all this, what needs to happen as a pump out some air, let us say fresh air is going to replace the air that was pumped out and again, new equilibrium between the gas and solid, pardon me, and also gas and water, and then you are again going to pump out. So if we keep doing that, it is going to take me around a two and a half years to be able to pump out the relevant aspects here or pump out the relevant benzene here. So I guess with that, you know, I am going to move onto the next topic.

Let us say, we are going to look at a particular case study, but because I am almost out of time here. Let us see, I will look at the case study later and we will go ahead and look at this particular of the next topic or introduce the next topic briefly. So the aspect that I am going to look at let us say is obviously going to be natural corollary of looking at, what is it now soil vapor extraction out, so again what is one of the advantages of using soil vapor extraction.

Now you know, you are obviously adding air or oxygen here, and so that typically depending upon the type of contaminant, is going to promote here a natural process. Let us see, or the Biodegradation. So obviously the next aspect we are going to look at is going to be bioremediation, well we did talk about natural attenuation, but that was mainly in the context of the relevant aspects with respect to groundwater contamination.

But here obviously we are going to look at, what do we say, aspects like, you know, the vadose zone, just the sediments, obviously not just the groundwater contamination here. Let us see. So we will look at that when we look at some of the basics again. So some of the aspects might seem similar or, because obviously the principles are the same here. So let me look at what I have here.

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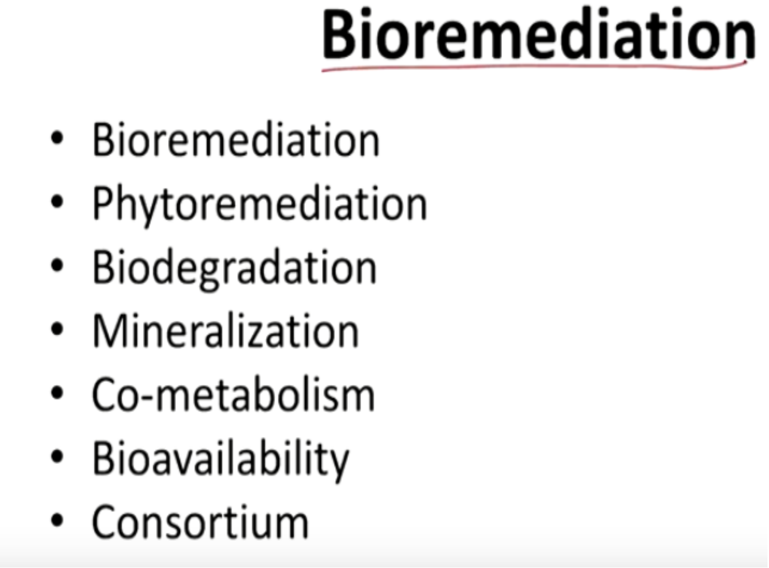

Bioremediation

- Bioremediation
- Phytoremediation
- Biodegradation
- Mineralization
- Co-metabolism
- Bioavailability
- Consortium

So when we look at bioremediation or talking about bioremediation, what is it that you know, referring to or what do I need to understand that? So it is bioremediation. So it is the use of let us say living organisms. Let us see, one aspect is living organisms two either degrade or immobilize the relevant contaminant. So what is it that we are looking at? We are looking at either degrading, or even a immobilizing the relevant contaminant. So one aspect that needs to be kept in mind is that when we are talking about Bioremediation, we were talking about living organisms.

So that does not mean we are only limiting ourselves to microorganisms, so the definition can also include let us say living plants, and that context, when we are looking at only plant, let us say we call that or are you also referred to that as phytoremediation. So what is phytoremediation? If the use of living plants let us say to degrade, or transform from one phase to the other.

When I say transform, I am typically referring to transform him from one phase as in from the, from being absorbed onto the soil or in the aqueous phase into the plant. Let us see. for transformation, let us see. or immobilizing it. so there are some fine, definitions here, but that is something to keep in mind. What are they now? So bioremediation more or less living organisms. It can be either micro organisms or plants and what is the end product?

We either end up degrading the relevant contaminant or at least make it immobile or we transform it into those, what did we say? Compounds which are obviously different from the original compound. Such that you know this particular contaminant cannot be transported. But in the case of phytoremediation, what are we referring to? Only when we apply or you know, look at the usage off living plants.

Let us say do I the degrade transform let us say, or the chain, the phase of the compound let us say or immobilize the content, so fine definition you no distinction here and that is something to keep in mind. So typically when we look at what do we say Biodegradation, let us see, we are looking at Lhotse obviously as the name indicates degradation. So here we are typically referring to, let us say when we say biodegradation, you know, a biological process used to, what do we say? degrade the compound, just degrade the compound.

There is a finite difference here. We are going to look at that, so we are going to transform the compound. Let us say from the parent compound and we are going to use biological process here and then there is something called Mineralization. Let us see, what did this here Mineralization is when let us say you are going to, let us say degrade the compound to such an extent that you are going to just, end up with CO2 or H2O so on.

You are completely mineralizing the relevant compound now. So here we have partially not no more partial degradation, but complete degradation, so that is when you call that particular system to be you know Mineralization. I guess. So that is a difference between Biodegradation and Mineralization. So Co-metabolism for example, let us say, you know, why is it that microbes want to, you know, facilitate the degradation of various, you know, contaminants or such because they want to derive energy, and for that they use their enzymes, and enzymes typically, you know, again, for their metabolism, they require this.

But when we says co-metabolism, let us say, you know, there are cases when buyer, let us say, due to the shape of the contaminant or such degradation does take place, let us say. But the energy from that particular degradation is not what we see used by the relevant microbe. So in that context, we referred to it as co-metabolism.

So bioavailability, let us say a refers to the interaction of the relevant compounded when I say interaction, it also means I see the degradation of the compound or any toxic effects of the relevant, compound on the relevant bacteria too or microbes pardon me, and such cases, let us see these interactions of this particular component let us say the transport of the contaminant, it is not just limited to only transport to my understanding.

There are other aspects involved too, like what is it, the toxicity or the effect of the toxicity of this contaminant to the microbe, and it is the ability to degrade and so on and so forth. They come under the category of bioavailability of the relevant components here for the relevant microbes now, So Consortium is I believe when you how different, you know, mixtures of four different types of microorganisms present and you would typically call that as a consortium, I guess.

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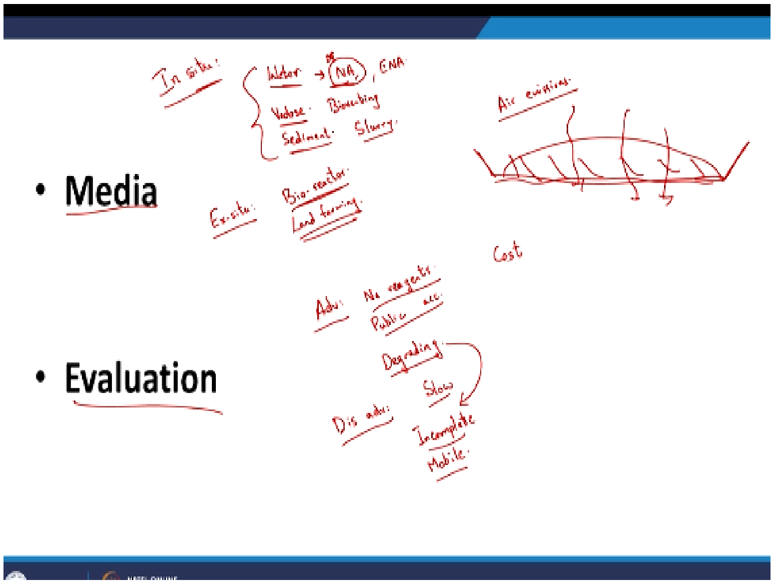

- Media
- Evaluation

So let us move on. What is it that we are going to look here is what are the different media that we are going to look at? Obviously we are going to look at water contaminated water. So in that context we also looked at, we already looked at either natural attenuation or you know Monte natural attenuation in the context of what do we say a remediation process typically. By law, you know, abroad, but typically in Indian context you have for applicability in Indian context we call that the natural attenuation. We also looked at the enhanced natural attenuation.

So this was with respect to water, obviously now we are looking at the various zones under saturated zone or even the sediment. So here again, typically we look at bio venting or such. Let us see. So all these are in-situ more or less. All these aspects are in-situ processes now, so we are looking at the in-situ process for water and radar zone typically, again we look at bio venting and such. For sediment let us say, what do you do? You try to form slurry. Let us say you add some water form is a slurry, let us say if possible on the site itself and then try to promote the not promote, let us say, yes, I guess you can call that promoting.

You are going to promote to what we see degradation of this particular relevant contaminant. Let us see. And obviously you can also have ex-situ as in you can going to excavate the soil, let us say. And then you know, try to remediate that in a bioreactor, so bioreactor, depending upon the type of your needs, let us say, or land farming, but when in the case of land farming, as in when you apply this particular contaminated soil.

Let us say on a particular patch of land and try to remediate that by relevant means. Let us see. One aspect you need to consider is that, let us say if this is your uncontaminated soil and you are dumping your contaminated soil out here, let us say. Obviously as we know, again, leaching can occur and you can how contamination of the areas beneath it or even the groundwater. So you need to look at having an impermeable layer and so on and so forth.

Those are the aspects that need to be taken into account when you are looking at land farming and so on and so forth. Again, due to land farming, one aspect that needs to be looked at is the emissions into the air and that is a critical aspect. And the typically there are thresholds but again, in the Indian context we are not so far advanced. But again, as I mentioned, you know the objective of this course is that if enough people are aware that there are considerable number of technologies out there that say that are already widely practiced.

And it is only the lack of transfer of technology, let us say from areas where it was applied to, you know, our Indian context, you know, I guess you can play the role of policy or decision makers. Again, that is one aspect out here. So Media in-situ and ex-situ, water, vadose and sediment, and so on and so forth and evaluation. I guess I am almost out of time, so I will wrap this up. As in what are some of the advantages now?

So typically it is that, you know, you are not adding any extraneous reagent, no extraneous reagents typically, typically anyway. Again, I say typically because there are other cases obviously, so no reagents and typically thus you are going to have greater public acceptance. Public acceptance is typically higher. And that is one aspect to keep in mind. And typically you end up with the actually degrading the compound. More often than not, you have degradation of the relevant compound.

And what are the disadvantages now? So typically it is slow, it is slow, and the degradation, let us say, might typically be incomplete. And some of these process, let us say that, you know, Biodegradation leads to let us say, or causes, let us see, can even make the contaminant more mobile, so these are some of the aspects, but typically what is the overriding aspect? That is the cost.

And in that aspect, obviously bioremediation typically place or you know, is at the considerable advantage because you know, other than wanting, you know, you are not really looking at a great deal of aspects or putting in a great deal of variables. Let us say changing a great deal of variables now, so obviously monitoring will be required, and then there are some of the disadvantages, but we look at those aspects later.

But I guess I am out of time, so we will continue this later and also look at some of the relevant case studies for both soil vapour extraction and for bioremediation once we look into that in greater detail. I guess with that, I will end today’s session and thank you.