# Environmental Remediation of Contaminated Sites
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## Lecture – 51
## Soil Vapor Extraction: Part-I

Hello everyone, so again welcome back to the latest lecture session. So a quick recap of what we have been up to you know and during this course let us say because that is going to more or less lead I to the relevant topic we are going to discuss today right so what have you been up to.

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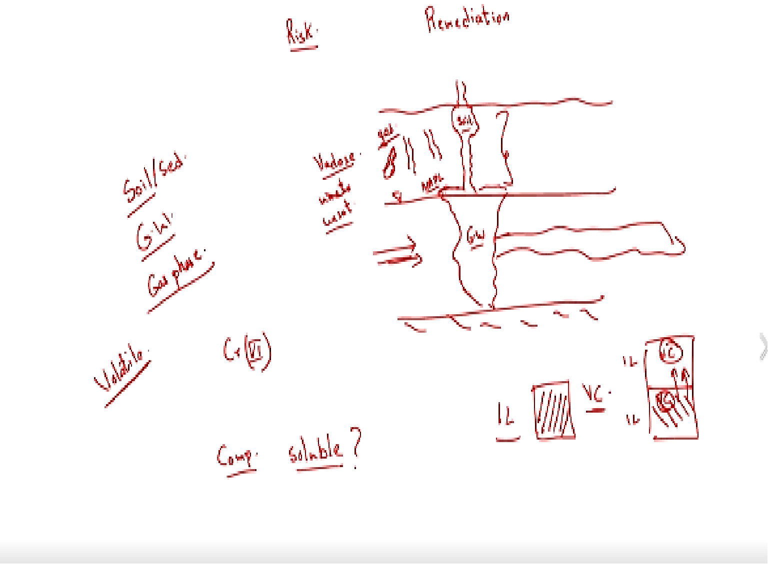

As and we looked at relevant risk assessments and relevant loss and so on yes and then we moved on to remediation right and the context of remediation we looked at two aspects what were they as in let us say this is your soil surface let us say and let us say this is your ground water table again typically there is going to be a gradient but now we are assuming you know I am assuming here that there is no gradient.

So let us say when you know you have any particular spill here let us say right depending upon the type of compound let us say it can reach out to this particular groundwater depending upon if it is LNAPL or DNAPL let us say right. It can lead to contamination of the groundwater so groundwater is contaminated here and obviously as ground water you know is going to flow let us say you are now going to have a plume right contaminated plume right.

And obviously as you can say in this region you are also going to have contaminated soil here right. So until now obviously we have looked at those cases when initially we looked at those cases when groundwater was remediated how do we go about remediating such scenarios or sites and then we looked at aspects let us say that primarily involved what do we say remediating contaminated soils right.

And obviously many of these techniques go hand in hand right and in general let us say you might have you know sensed by. Now there is no particular case let us say when you are rarely do come across the case when you have just groundwater you know that is contaminated or just soil that is contaminated sometimes just the soil contamination yes without groundwater contamination depending upon you know the extent of time that has passed since the release of the relevant contaminants let us say right.

But as we look at this particular aspect of this general diagram or figure that out how here so what is another phase obviously that can be contaminated let us say. As in we can also have a NAPL right this is the NAPL that acts as a source or reservoir so soil is contaminated groundwater or NAPL itself can be present as what did we say a different phase let us say right. But what is another in that phase let us say.

That obviously that can be you know contaminated here so that is obviously in the vadose zone or when you have relatively unsaturated zones let us say. So we have vadose zones let us say and obviously here let us say you have porosity here right the soil is porous right and here you obviously are going to have gas right or you know air entrapped here. So you are also going to have what do we say the relevant contamination of the gaseous phase.

So until now we have typically looked at soil or sediments and then groundwater and obviously also we are going to now we will look at the contamination of this particular gaseous phase let us say or the air entrapped right and again obviously not all contaminants let us say will lead to the particular contamination of this particular gaseous phase let us say or the vadose zone if I may call that let us say in this case right.

Why is that let us say right for example if I have metal let us say right let us say I will go with the chromium 6 let us say right so this is typically highly soluble it is not hydrophobic right it is typically highly soluble so this contaminant obviously would want to stay in the acquiesce phase or in the water right it would obviously not want to you know stay in the gaseous phase or typically not be absorbed onto the soil now right.

So obviously when you have such kinds of contaminants you do not need to be concerned about let us say the contamination of this particular air and trapped in this particular zone right but obviously which kind of contaminants do we need to look at right. So typically hydrophobic compounds that said they do not want to stay in the aqueous phase and obviously they look for let us say the organic matter as we looked at let us say.

Again there are other aspects involved here about why or what the driving force here but we are not going into that in this course anyway right. But again so obviously some of these hydrophobic compounds are also volatile let us say right some not all hydrophobic compounds are volatile. So when I say volatile what do I mean by that legacy as an it does not want to stay in the aqueous phase let us say right it wants to stay in the gaseous phase.

So let us say initially I had taken a compound of let us say vinyl chloride let us say right and that is only in the water let us say right this is a one litre assume that and this water is contaminated with vinyl chloride and I put it in a 2 litre container and you know and this is 1 litre and this is also 1 litre here. So let us say I let it reach equilibrium as vinyl chloride is very volatile so the equilibrium might be reached within a few what do we say minutes right.

So wat is going to happen after some time is that you know all the are not all pardon me almost all the vinyl chloride that was initially in the aqueous phase will change phase and going to the gaseous phase right again. So here are the compound water lies so again that is the case or for these kinds of compounds you know we are obviously concerned with the relevant contamination of this particular gaseous phase or the vadose zone let us say right.

So now we are going to look at let us say how do we you know address this particular case let us say right so by remediation kind of probably not here at least the gaseous phase right so how do we go about it so what did we do when we had a what do we say a compound that was highly soluble let us say what did we do in that particular case or context right. As in when we had (()) (06:29) chromium let us say right you can think of pumping the chromium out right.

You know that is one aspect I think we even looked at one particular example in Ghaziabad where they were looking at it I get along with let us say or in conjunction with I think by remediation right. So again you know soluble say it wants to stay in the aqueous phase on the water so you pump out the water. So similarly here let us say I know if you have a compound that wants to stay only in the gaseous phase are mostly in the gaseous phase what do you do.

Well again you are going to extract the guests right its not pumping out the gas or you can call that too so you are going to extend the gas right so the next aspect obviously that we are going to discuss is going to be.

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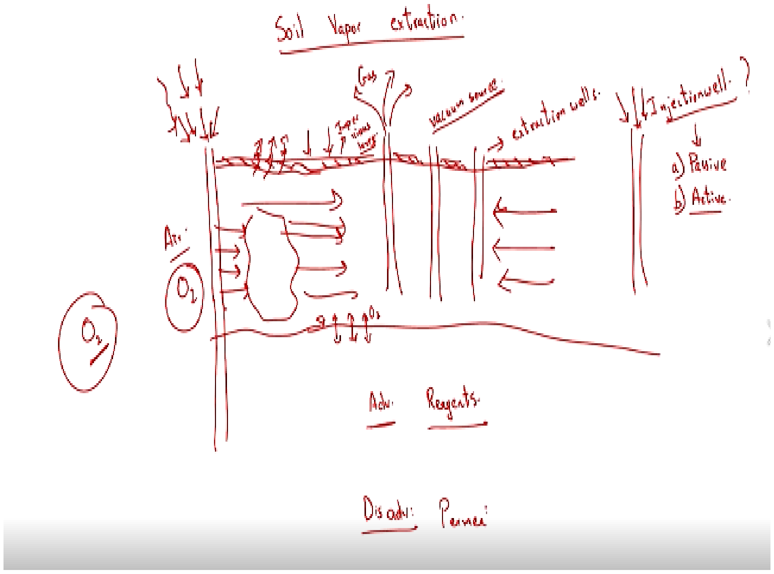

Soil vapor extraction okay right yeah so this is what we are going to look at so we are going to look at extracting the soil vapor. So let us look at some of the relevant aspects so let us say this is my relevant surface here let us say soil surface and all this is the subsurface obviously let us say my ground water is somewhere out here let us say and this particular zone you know the gas here is contaminated let us say.

So what am I going to do I am going to have to have a vacuum source right a vacuum source yes so I need to be able to pump the gas out right? So for that there are two ways to go about it you will either have a vacuum source and then as you know the gas flows towards this particular vacuum so a source pardon me right you are also going to have these extraction wells okay right and these extraction wells are going to remove your particular gas you are right.

So you are going to have extraction wells right so sometimes you can double up and how would the vacuum source and the extraction wells in the same what did we say set up but I think depends upon the site and so on right. So obviously you are going to have this particular setup and what else can you do to make this system work better right. As you are drawing something out let us say you know there is always going to be some resistance source time again right.

So you will need to have let us say an injection level even if I can call it an injection well okay injection well right and what its role now it is going to let and r the air to come in with right. So you had a drawing air towards these vacuum source or toward this extraction wells where you are extracting the gas. So obviously you are going to have to supply air and that comes through from the extraction of the this.

So that so let us say if my contaminated zone is this one so once I remove this contaminated gas I am going to again provide fresh or uncontaminated air that is again going to come in contact with either the contaminant or any other relevant aspects there. And again the contaminant is going to change phase into the gaseous phase and then I am going to remove that right so again its a cycle the more or less.

So with respect to the injection wells there are two cases obviously as you can well logically deduce the either passive or active. So passive and active again there are self-explanatory okay passive okay let us talk about active in the first case active I am going to pump air in let us say I am going to pump air pass through let us say you know its open to the atmosphere and again depending on the design let us say it is going to be able to draw an air in pardon me right.

Again an active and passive here right so in this context what else do you need to do let us say to be able to remediate this particular what do we say system which right you also need to have an impermanence impervious layer here at the top right. Again two aspects first when you notice that this particular vadose zone or the gas there is contaminated you obviously do not want that particular contamination to escape out you want to control that right.

And once you start pumping your relevant what do we say contaminated gas out again you do not want to have right level of interference from the outside what do we say environment too. So you again need to have an impervious layer here right impervious layer right okay. So what are the major aspects that obviously are required you need to vacuum source you need an extraction well right.

And obviously you need an injection well and what else do we have again the impervious layer right again in the context of injection wells we have either the active or the passive voice right. So this is more or less the you know what do we say summary if I can say of relevant system right in what way it can also aid other what do we say systems now right and I think in the context of maybe bio-remediation let us say we did look at this briefly.

But how does this again help bioremediation let us say right so this aspect is that if you have other contaminants let us say right or do you know if some of these compounds are relatively soluble are you know reduced compounds what do you need do you need an electron acceptor typical electron acceptor it is oxygen let us say. Beneath the subsurface or beneath the sub surface typically oxygen levels are relatively low right.

So while you carry out this soil vapor extraction what do you say happening here you obviously say that you are introducing let us say air into the system now right or I am obviously introducing oxygen into the system. So this oxygen based upon where you are pumping this what do we say air in either sub into the aquifer or let us say just to the what was top of this particular act full if it is about the top you will have some what do you say oxygen transfer into the water right.

Based on again what do we say phase change let us say right you want to have equilibrium between oxygen and this particular vadose zone and oxygen in the groundwater table you will have that art fuel pump what do we say air into this particular act for itself directly you are going to have righter oxygen concentrations in this particular act for and that can aid your remediation process because it can further bioremediation.

Or it can enhance by remediation especially when the compound are reduced and you want an electron acceptor right so that is one point where case against soil vapor extraction typically has been saying that you tend to increase the or enhances the effects of a natural adnation right. So that is one aspect to keep in mind. So let us look at some of the advantages of this particular system so the major advantage obviously is that you are not introducing any reagents right.

So no reagents as in no chemicals right nothing out there right so you do not need to be concerned with what do you say adding any you know involuntarily adding contamination or any contaminant or residual contamination as in with respect to soil washing we had to put in surfactant so even after you pump out all the surfactant obviously you are going to have some residual surfactant again that can cause issues.

But with what we say soil vapor extraction obviously you know that is not going to be the case you know that is one you know remarkably good advantage out there. But what is the disadvantage let us say right what is the disadvantage you face. As you could have sense you know you need to how are you know the system needs to be such that at the site needs to be such that you know you are going to are that its going to allow air to flow through right.

So it needs to be real to be permeable right site needs to be relatively permeable right so that is one key aspect practical aspect that can affect the relevant efficiency of your particular system here right. So that is something to keep in mind right so now let us move on and look at obviously the relevant balance right. Again we are going to look at the case when equilibrium has been reached.

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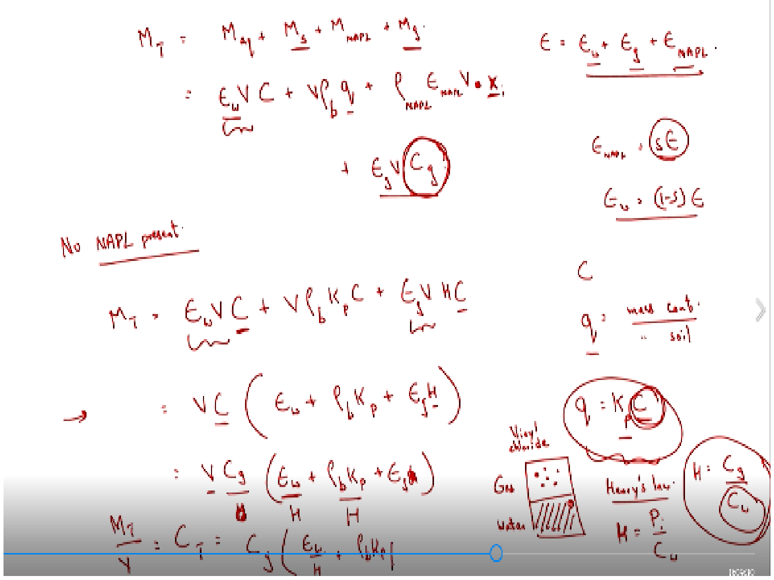

$M_T = M_{aq} + M_s + M_{NAPL} + M_g$

$= \varepsilon_w V C + V \rho_b q + \rho_{NAPL} \varepsilon_{NAPL} V \cdot X_i + \varepsilon_g V C_g$

$\varepsilon = \varepsilon_w + \varepsilon_g + \varepsilon_{NAPL}$

$\varepsilon_{NAPL} = s\varepsilon$

$\varepsilon_w = (1-s)\varepsilon$

No NAPL present.

$M_T = \varepsilon_w V C + V \rho_b K_p C + \varepsilon_g V H C$

$= V C (\varepsilon_w + \rho_b K_p + \varepsilon_g H)$

$= V C_g \left( \frac{\varepsilon_w}{H} + \frac{\rho_b K_p}{H} + \varepsilon_g \right)$

$\frac{M_T}{V} = C_T = C_g \left( \frac{\varepsilon_w}{H} + \rho_b K_p$

$C$

$q = \frac{\text{mass cont.}}{\text{" soil}}$

$q = K_p C$

Henry's law.

$H = \frac{P_i}{C_w}$

$H = \frac{C_g}{C_w}$

So typically what do you have let us say we have total mass or Mat time =0=mass in the aqueous phase+ mass in the soil + mass in the NAPL phase right and now let us say but you know soil vapor extraction you obviously also going to how are pardon me even without soil vapour extraction in this phase case of a volatile compound you are also going to have the relevant compounds present in the gaseous phase right.

So let us just write down these terms here so let us say here unlike earlier I am going to define the total porosity as porosity of what we say in terms of water gas and that occupied by the NAPL right so its slightly different earlier we more or less took this particular case as how did we understand this S times porosity here right that is how we looked at it and for water we are more or less considered to be 1-s times porosity.

So but because we have another term here we are going to look at total porosity let us say and I am going to say the three fractions are you know occupied by water gas and the NAPL. So let me take the down here so I need the volume of what do we say water so that is porosity of what we say so that is going to be the volume occupied by waters right times the concentration in the water right C is the concentration in the water + mass absorbed onto the soil right.

So how do I get that as we know volume bulk density of the relevant soil*q and what is q by now we should be able to understand this is the mass of contaminant per mass of soil let us say right so more or less the concentration absorbed onto the relevant soil let us say right. So again as you know soil and contaminant in the water let us say you are going to have an equilibrium right. So q is going to be in equilibrium with C.

C is the concentration of the contaminant in the water and typically we have looked at or assumed that its a linear relationship and it is what do we say explained by the partition coefficient right. So that is something we have looked at so again we can come back to that and NAPL I think we again how does the density of NAPL right again the volume occupied by NAPL right * the mole fraction right.

Obviously if it is a pure what do we say NAPL the mole fraction is going to be=1 right. So I think that is something that we looked at and now that we have gaseous phase let us say what do you have here. So again we have the concentration of the relevant gas let us say our concentration on the total not concentration pardon me the total volume or you know fraction of this particular total volume is occupied by gas so that is what we need here.

So I am going to multiply the total volume by the porosity that is occupied by gas let us say or the gaseous phase times concentration in the gaseous phase right. So these are the terms that we have so we will look at two or three cases because you know these are what we would come across out there. So let us say in the first case I will just look at the case when there is no NAPL present let us say right.

So this total mass let us say is nothing but let us just write down terms that we have here. So volume occupied by water times concentration of the relevant contaminant in the water+ volume right bulk density and q, q as we know from here is in equilibrium with the concentration of contaminating the water right and now I am assuming there is no NAPL and I am going to have these terms here right.

So rho g v which is volume of gas times concentration of gas let us say. But again we want to obviously be able to express the relevant terms in terms of the variables that we are used to and what that typically we are looking at or expressing them in terms of the concentration of the contaminant in the water or the aqueous phase. So let us just look at how to express this concentration of the gas in terms of concentration and the of the contaminant in the water.

So as we looked at earlier let us say the example that we looked at briefly vinyl fluoride. So let us say if I let it equilibrate between the water and the gaseous phase. So this is the gaseous phase and this is let us say the aqueous phase of the water here what do you observe the vinyl chloride let us say even though its highly volatile and most of it let us say is present in the gas you will still have some vinyl chloride present in some vinyl chloride.

Let us say which I am going to represent by this that is going to be present in your particular water too right say again that is going to be an equilibrium between the gaseous phase and the aqueous phase right and what is the relationship that we typically have that gives us you now this particular relationship so that is particular typically Henrys law and from there we ended up getting the henrys constant for different.

What do we say compounds say again a henrys constant has different units so depending upon the relevant units of Henrys constant it can even be diamond unless it can be pressure per mole right or it can even be what do we say concentration of water by gas? But typically let us say pressure partial pressure of that particular gas/right the concentration of the contaminant in that particular water let us say or in the aqueous phase.

Or henrys constant depending upon units is also concentration in the gaseous phase/concentration in the water let us say right. So that is what we have here so for now we are going to use this particular nomenclature now right. So let us see how I can plug this in so obviously here I need to I am looking for expressing concentration of the gas in terms of concentration of the water right.

So here as they can say its nothing but henrys constant times concentration of water because I expressed it as C I am going to leave that as C now right. So I take this particular term out right as an I am going to take VC out of this particular set of variables and now I am going to simplify that so porosity occupied by water let us say rho b kp + gas and henrys constant again henry is constant as I mentioned has different units.

So you need to look at the kind of units you have or you know you need to if you are looking for a ratio of concentration of gas to concentration of water depending on those units you need to look for the relevant henrys constant and foremost compounds out there are almost all we will have the relevant henrys constant where at different temperatures and so on right. So again we have this out here and this is what we typically have right.

But one aspect to keep in mind as an we similar to the vinyl chloride case that we just looked at as in here we looked at the vinyl chloride case right and what do we observe here let us say right that if its a volatile compound typically let us say most of the concentration will be present in the gaseous phase So rather than expressing this particular set of variables in terms of concentration of water its better to express it actually in terms of concentration of the gas here.

So I can express this as V times concentration of gas/the henrys constant right times porosity of water rho b kp+rho g times h right so this is what I ended up with if I take the henrys constant and so this particular set of variables I end up with something like this right. So again how else can I simplify this further so M total/V the total mass M total is the total mass/total volume. So that will be the total concentration so that just gives us an idea let us say right.

You know obviously you know that the concentration is spread over or the contaminant is in three phases water soil and in the gaseous phase. But total concentration sometimes just gives you an idea of the relevant system right is obviously nothing but concentration I took this volume out to the left hand side concentration of gas right by henrys constant rho b kp/henrys constant + porosity of this particular occupied with this gas.

So this is one particular case that you know that one set of equation that we typically use widely anyway right. So now until now we have looked at the case when no NAPL was present right and again why do we need such particular cases or systems now right. Again what is the reasoning behind you know having to analyse for it or you know break down in these terms because let us say site is contaminated.

And you want to deploy your relevant resources time and manpower right and what do you do you need to look at or prioritize you know which aspect to look at here right. So obviously you lead to say which particular phase has you know the greater what do we say fraction of the contaminant in it. So far that obviously I need to be able to come up with this theoretical calculations to know which particular phase is it that I am going to prioritize

And then address or try to address let us say right. So in those cases let us say to understand the system and unless system you are going to have to do or conduct such analysis.

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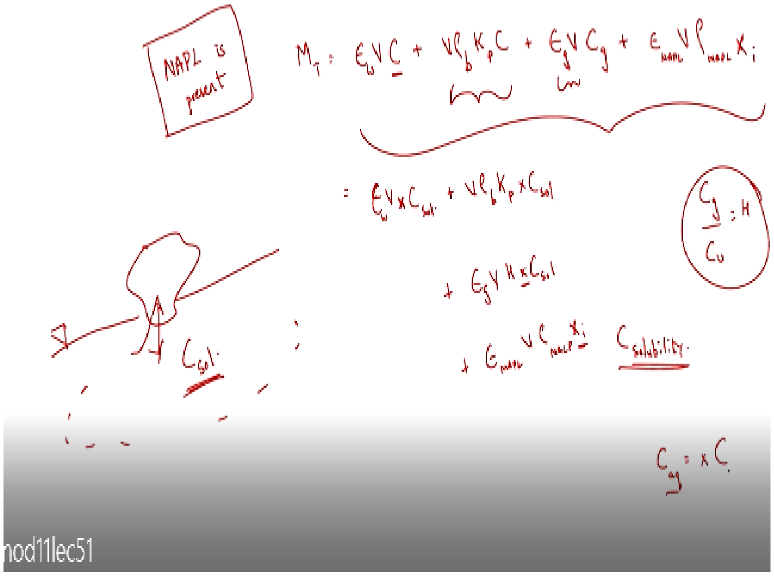

So now we will also look at the case where regenerated case when NAPL is presently let us say right okay so NAPL is present let us say so let us just write down the case that we had earlier so total mass is = what did we have here so I think we had epsilon or porosity of water times volume and concentration of water right and again we have V rho b q, q is nothing but kp times C this is the mass in the relevant absorbed onto relevant soil.

So in the gaseous phase so this is the volume of the gas times the concentration in the gas right so concentration in the gas/concentration in the water henrys constant right this is something that we have so if I can write it okay I will write it as concentration in the gas for now. And then again what do we say porosity occupied by this NAPL right times the volume and density of NAPL right* the mass fraction let us say mass fraction of that NAPL right.

So that is another aspect obviously to keep in mind when we have what do we say the relevant aspects with respect to the NAPL. But in this case what is one aspect that you need to keep in mind you if the NAPL is present. NAPL or even if I say its or if I consider it to be a pure NAPL let us say what is going to happen you have the pure NAPL present and that is going to be in equilibrium with your water.

Let us say if the equilibrium has been reached maybe because enough time have not passed what did we say the system has not reached equilibrium maybe its relatively far from equilibrium but let us say we are going to look at the case when there is an equilibrium between the NAPL and the relevant water let us say so then what is this C going to be right so that would be the solubility.

Let us say solubility of that particular compound if the relevant equilibrium has been reached right but if the equilibrium has not been reached right it will typically be less than the solubility right. As in there is only a particular threshold or maximum concentration that water can hold with respect to any particular iron or compound let us say right. So if the equilibrium has been reached and you have the pure NAPL.

So if you have the pure NAPL and ground water right in contact if equilibrium has been reached the concentration here of that compound will be the solubility right. But you know typically let us say maybe not enough time has been reached or you know to for the relevant contaminant to diffuse to all this particular region out here that takes time let us say. So let us say you know your particular concentration in the water has not yet the solubility levels.

So I can say that this concentration is going to be equal to a fraction of this particular solubility let us say. So solubility is the maximum that can be but let us say if equilibrium has been reached out its relatively newer equilibrium though I can say its some fraction of the solubility right that is how we are going to express it as this is that fraction x let us say +V rho b kp times x times C of solubility+ again rho gas V Cg is nothing but henrys constant*concentration of water.

Concentration of water we are expressing it in terms of solubility so write this x times solubility plus obviously again the mass and the NAPL volume density of NAPL and mole fraction of this NAPL again keep in mind this X is different from here again what is this x let us say you know what are we trying to use that represent as in the concentration there is particular concentration on the contaminant in the relevant aqueous phase.

But let us say even though the NAPL is in contact with your water let us say equilibrium has not had been reached right we want to obviously express in terms of concentration of solubility to be able to understand the system better and in that case I am just using this expression as you know concentration actual concentration in the water or in the aqueous phase is x times the concentration or the solubility.

Let us say right so that is how we express that as and you know you can analyse the system from this particular point of view I guess right. So then now I guess i know are almost out of time so we will look at the or you know talk very briefly about the design and go ahead from that let us say right.

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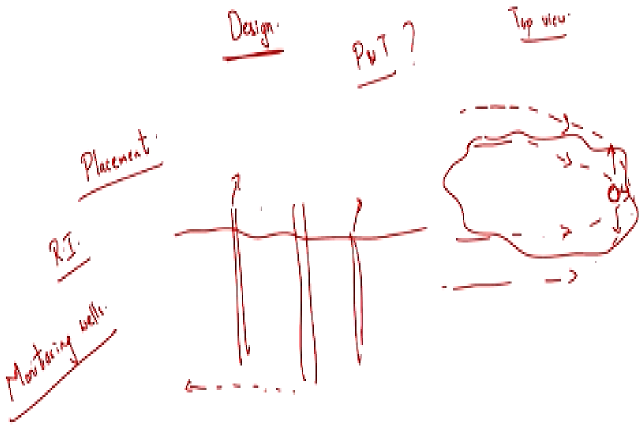

So we let us say you want to design this particular system the remediation system let us say right so obviously what do you need or you know think of what we did in the pump and treat let us say what did we do in the pump and treat now right. In that case if you remember let us say if this is the top view and let us say you know how my contaminant plume like this right and I can place one particular well here right based on the Avondale at all design.

And depending on the flow right let us say I can capture this particular flow bot right that is something that we looked at right. This is the boundary of the flow paths that can be captured and so on so what were the key aspects there as and we need to figure out or we had to figure out how many extraction wells to how what is the right of extraction that we needed to how and what is the placement of this particular extraction well right.

The placement here that is something that we had to look at right so similarly again what are we going to look at we are going to look at placement let us say right. So for the placement let us say you know what are they going to look at let us say right here right you are obviously going to have to understand let us say are you know you need to consider let us say those particular areas where the vacuum is still what we say about I know certain threshold values.

As in if this is my surface and I am applying vacuum here let us say so there is going to be pressure drop but the further I move away from this particular vacuum source the pressure drop is going to decrease right. So let us say if I am pumping air out from here or you know I am introducing a vacuum source here as i move away from this particular source obviously the effect is going to be relatively less.

So based upon which particular source or type of a what do we say literature you look at there are different ways to calculate what is the you know radius of you know influence if I may call that right. So you are going to have to calculate that radius of influence let us say and then look at relevant placement and so on and so forth right. Obviously one aspect is that do you also need to have monitoring wells right.

You obviously need to have monitoring wells other than just your extraction wells and so on right yes. So again just a quick recap before we you know close the you know or end the session for today. So we are going to have your what do we say now your vacuum source extraction wells impermeable layer cap right and also injection wells active or passive right and if required you lost how multiple monitoring wells right.

And obviously there are other aspects to be looked at as an when you pump it out you need to look for or consider the off gas treatment or treatment of this particular gas. And also depending upon the system if you are also pumping what route you will also need to look at separating the water and gas and then treating both the water and the gas right. So depending upon how you set up your system you might end up pumping out.

Let us say both the or extracting both water and gas right and let us say or you will have some water entrapped too depending upon the depth that which you are looking at let us say and let us say then you are going to have to look at separating the water and gas and then treating both these phases right. So again these are different aspects to be involved but we will look at the design and maybe an example again in the next session and that is it from me for today and thank you.