

**Unsaturated Soil Mechanics**  
**Dr. T.V. Bharat**  
**Department of Civil Engineering**  
**Indian Institute of Technology, Guwahati**

**Week – 12**

**Lecture – 36**

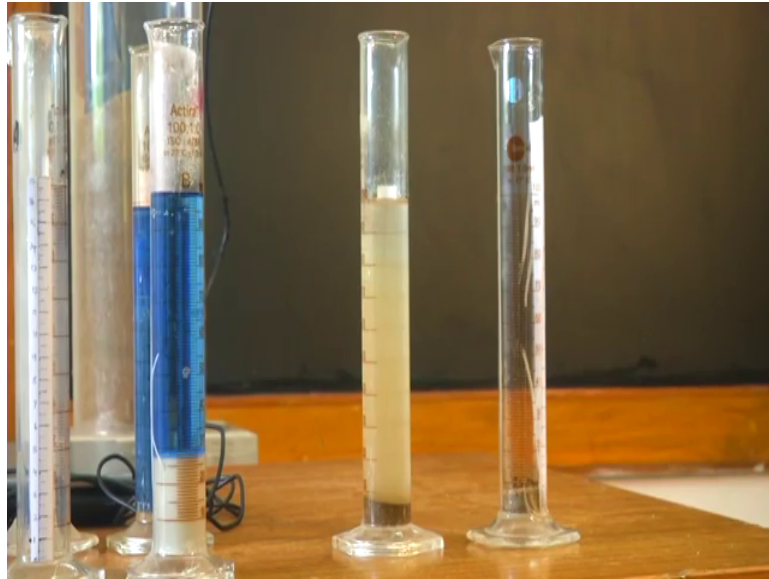
**Demonstration of Various Experiments Related to Unsaturated Soil Mechanics**

Hello everyone. We have been discussing the volume change behaviour of soils especially clays. Today, let us understand with simple experiments how the volume change of different clays can be understood. Let me demonstrate the variation and volume of the soil in water right kerosene, which is non-polar. Here we have 3 different soils one is sand which is inert which does not react to water or kerosene and we have bentonite, which is rich in montmorillonite, which reacts with water and kerosene again because it is non-polar it does not react.

So, the clay water interaction because of the mechanisms involved in clay water interaction, the change in the volume of the soils can be understood with simple experiments which is called (Refer Time: 01:30) index or equilibrium cement volume. And, we have kaolin which is rich in (Refer Time: 01:37) mineral. The volume of this (Refer Time: 01:40) minerals in water is smaller than in the presence of kerosene.

So, let us understand why the volume this soils of clays change with different interactions with water and kerosene. I have my research team here they would help me in doing this test that is understand now.

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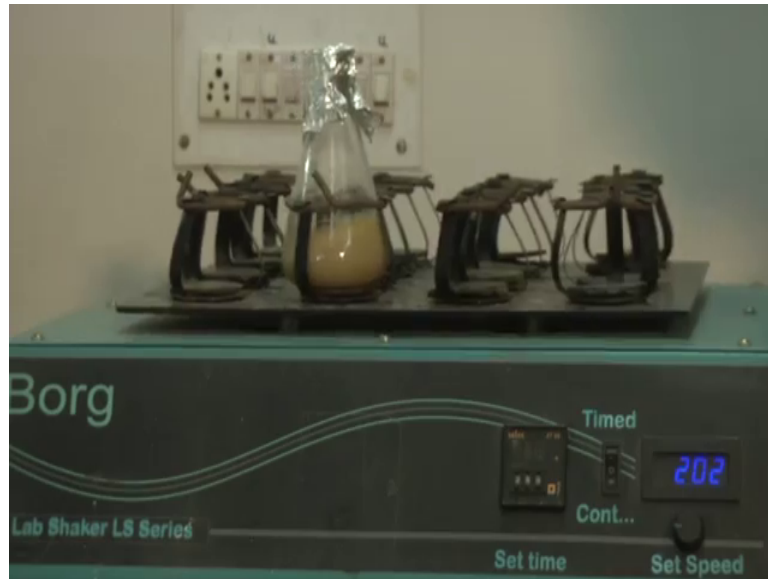
We have 2 cylinders; in one cylinder we have sand dry sand have to and in other cylinder will have sand kept in water. Here you can see the volume of the sand in both the cylinders is nearly same. So, that is because of sand has not react with water. So, because of that the volume is merely same, another hand if we have bentonite let us see what happens.

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Here we have taken 2 gram of bentonite clay; we have a glass jar glass beaker, soil will be mixed on with water.

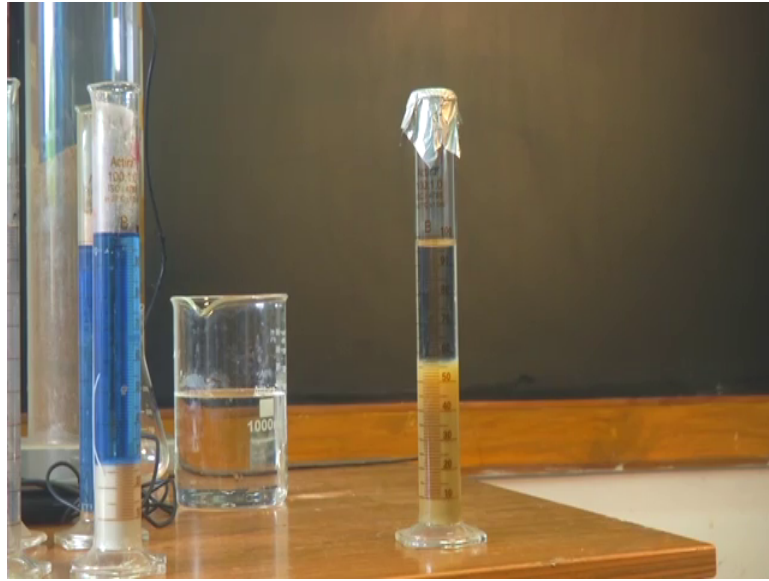
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But; however, for mixing we require lab shaker. So, that thorough mixing is possible the dry sample is added to glass beaker and water is added.

So, now this is normal mixing is not possible. So, therefore, this will be placed in a shaker and will be continuously stirred or mixed in the orbital (Refer Time: 03:20) Here, we can specify the speed and we can set the time. So, normally so, this is how this sample is placed and we can set the speed. And, as slowly speed is increased it will start shaking and considerable time is required for bentonites, for mixing. And, once the sample is thoroughly mixed this will be transferred into glass jar to make 100 ml solution and sedimentation will be allowed.

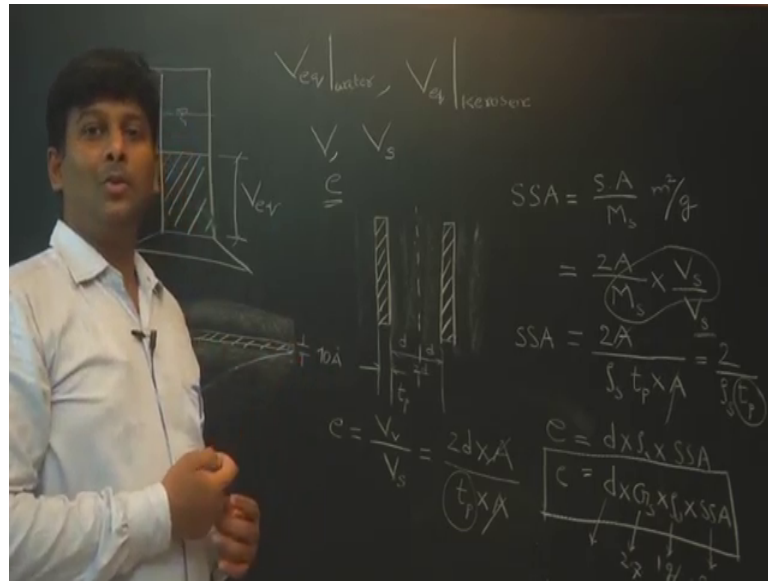
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Now, you have 2 gram of clay dry bentonite powder which is available in 100 ml glass cylinder. Finally, be thoroughly mix it again and then we let it settle for equilibrium, the particles slowly settle under gravity. This takes enormous time in case of bentonites, we have a clay water cylinder which is prepared earlier, much earlier which is shown now here.

So, here you can see that there is a clear water that is formed. And, you can see the interface between clay and then water. If, you look at the volume of the clay now this is significantly high. This is because the formation of diffused layers. Let me explain on the board now.

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When we have a cylinder, where we placed clay in it, when it is mixed with 100 ml of water, which forms a clear clay water solution at equilibrium. This is the equilibrium volume. If sand of that amount is taken and then put it in water, it does not exhibit that much of volume expansion or volume change, volume essentially remains same as we have just seen.

In case of clay volume expands and equilibrium volume is significantly higher. This is because when you consider individual particle or clay platelet, which is a thin cylinder particle or platelet. The thickness is around 10 angstrom units nearly one nanometer for smectite particles that is bentonite. And, this is a slender particle platelet; because of the negative charge on the surface, it has a formation of diffused layers around individual platelet.

So, the diffused layer around individual particle or platelet is significantly high the thickness could extend perhaps 50 to 100 orders of magnitude higher than the thickness of the platelet. It can be an extend to higher value depending on the surface properties of individual clay platelet or individual clay or a given clay, which defines the plasticity of the clay.

So, now electrostatic potential around individual platelet varies in this manner and this is a thickness of diffuse double layer, which is represented with small  $d$  around individual clay platelet. If, I have 2 clay platelets which is just started interacting each other. And,

they have diffuse double layers formed, now if this is the particle thickness or platelet thickness. And this is the thickness of diffuse double layer from 2 different particles; if one particle diffuse double layer thickness called  $d$ , then its total value is  $2d$ . So, we can relate this thickness of diffuse double layer with void ratio and from void ratio the equilibrium volume can be related.

So, it is very clear to understand how the equilibrium volume is such a significantly high value. So, here the void ratio we define void ratio as volume of voids by volume of solids. In this case if you consider the volume of voids as this is the volume of void space, this is particle, this is another particle. So, the volume of voids can be obtained cause this is the space which represents the volume of voids. So, the volume of voids can be obtained as  $2d$  times the surface area. So, which is  $A$  divided by the volume of solids that is thickness of plate times the area. So, area gets cancelled from the numerator and denominator.

So, essentially the void ratio is simply 2 times thickness of diffuse double layer divided by the thickness of the plate. If diffuse double layer thickness and thickness of the plate are known we can estimate the void ratio. However, we can avoid estimation of thickness of plate and plate by considering specific surface area which can be determined in the laboratory.

So, the specific surface area is nothing, but surface area per unit mass which has units of meter square per gram. So, here if I take the surface area of individual particle or platelet, surface area consists of this area this area and area of the edges. If I ignore the area of edges you have 2 times area divided by mass of solids, if I multiply with volume of solids and divide with volume of solids, I can write this as  $2A$  divided by density of solids. And, this volume of solids again I can write it as this is density and this volume of solids again I can write it as  $t_p$  times area again area gets cancelled.

And so therefore, specific surface area is nothing, but 2 divided by density of solids times thickness of platelet. I can replace this thickness of platelet from the previous equation. Now, I can write void ratio as  $d$  times  $\rho_s$  times SSA.

So, we got rid of  $t_p$  now, thickness of platelet now or this can be written as  $d$  times specific gravity times  $\rho_w$  times surface area specific surface area. Generally the

specific surface area of clays, like bentonites is very high, which can be as high as 800 meter square per gram.

So, therefore, this is significantly higher value may be 800 meter square per gram. So, this is the density of water 1 gram per centimeter cube and this is the constant value, it may be around 2.7 this is the case of diffuse double layer, which can be several orders of magnitude higher than the thickness of the plate. This may be around 50 times if we angstrom then 500 angstrom units or 1000 angstrom units we can use. And, if you calculate the void ratios will be significantly high we can be as high as more than 100.

So, similarly this void ratio can be related to the equilibrium sediment volume, because this is the total volume and knowing the total volume and volume of solids, we can relate this to void ratio. So, therefore, void ratio is related to the thickness of diffuse double layer and specific surface area. Because, once there is formation of diffuse double layer around the clay platelet. So, the interaction of these 2 diffuse double layers would govern the total volume of the soil.

So, as this diffuse double layer thickness is significantly high, the volume is significantly high. So, this can be verified by conducting an experiment in kerosene which is non-polar. So, therefore, there is no formation of diffuse double layers. So, when you conduct the experiment the equilibrium volume is significantly lower. So, this our equilibrium volume in water and equilibrium volume in kerosene or any other non-polar liquids.

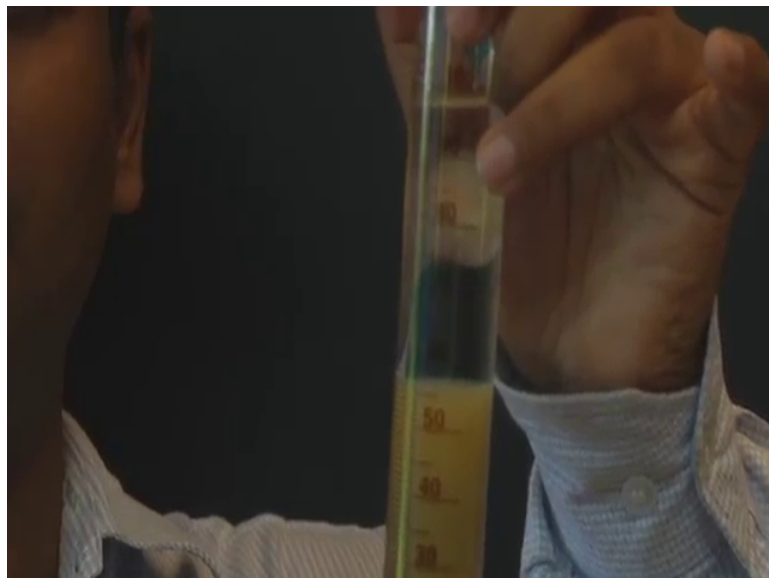
So, the difference between these 2 volumes would infer our (Refer Time: 14:01) the swell potential of the soil or how much it can significantly swell due to the clay water interaction or due to formation of diffuse double layers.

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So, this is difference between the equilibrium sediment volume of bentonite in water and kerosene.

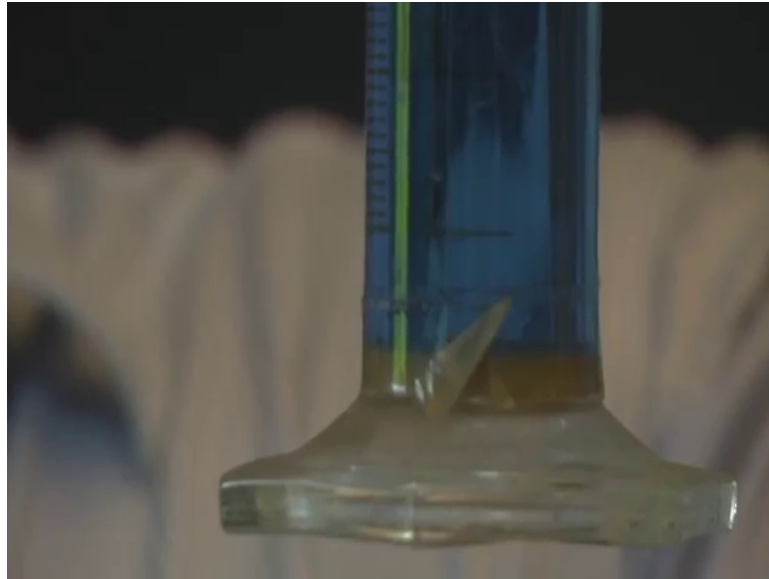
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In case of water the equilibrium sediment volume is significantly high somewhere here, still soil is about to settle and still it has not come to equilibrium and it may take further some more days, but anyways the equilibrium sediment volume will be somewhere here. So, this is the volume around 60 55 ml, around 55 58 ml is the volume, when 2 gram of dry bentonite powder is mixed with water, equilibrium sediment volume is nearly 58 ml.



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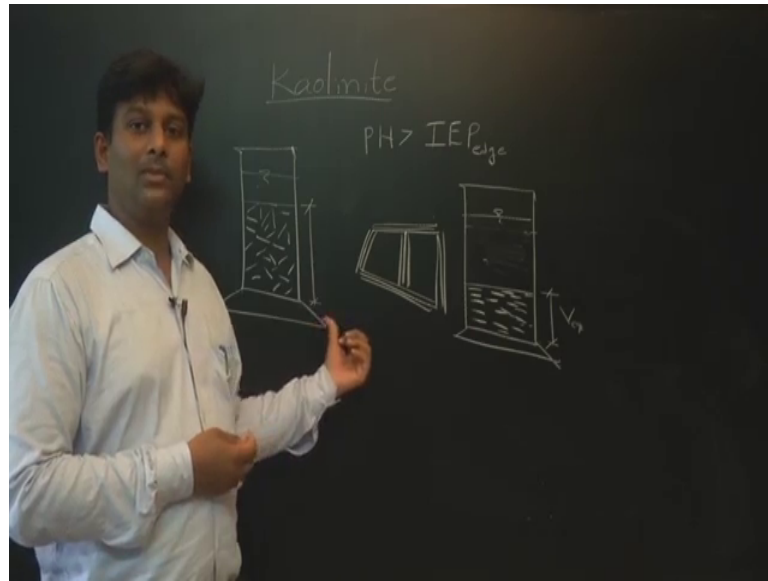


So, in the same powder, same 2 gram of bentonite powder when it is mixed with kerosene. So, the volume is significantly low. So, this is the volume of clay when there is no formation of diffuse double layers. So, the volume is non-measurable by this even, because this is much lower than even 5 ml.

So, this shows the potential of bentonite in the presence of water. We have been discussing the volume change period of kaolinite. Kaolinite in a peculiar manner it behaves it does not swell. However, it collapses or it exhibits collapse in the presence of water or water which has pH higher than isoelectric point of the edge.

So, generally if you take distilled water, the isolated point of the edges is about 3 to 4 and the distilled water pH is around 7 sometimes it may be (Refer Time: 16:20) 6.5 and 7. So, therefore, due to the changes in the charge in the particles, the particle interaction is different therefore, it exhibits a different behavior.

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So, if you if I consider kaolinite particle or platelet. So, the particle thickness or the platelet thickness would be around 10 nanometer nearly 100 angstroms units, which is nearly 10 times larger than the smectite particle, which is seen from the scanning electro-microscope.

So, now particle thickness is larger therefore, specific surface area is small, the specific surface area is smaller compared to the smectite and the specific surface area varies in the range of 10 to 12 for kaolinite and the (Refer Time: 17:09) is in between the specific surface area is about 18 meter square per gram. So, because the thickness of the particle would govern the surface area would influence the specific surface area. So, when the particles are smaller surface area and the cations change capacity is also small, because there is a strong bond between individual basic units of kaolinite of the 1 is to 1 mineral.

So, therefore, the charge is also compensated except that there is a small charge which is due to the isomorphism of substitution, which is called permanent charge, but which is smaller value. So, the ccs the cation exchange capacities would 5 millikilometer per 100 gram. Apart from the permanent charge the charges on the kaolinite platelet us would change depending on the interaction with different (Refer Time: 18:08), edges generally have positive charge and face has negative charge.

So, therefore, when the particles interact in dry environment particles would form or arrange themselves into this structure is called edge to face or (Refer Time: 18:32)

structure. So, this may be another (Refer Time: 18:35) particles and these are another particles. So, if you see there is a macro pore volume that exist between individual platelet us and there is a micro pore volume and this is the macro pore volume.

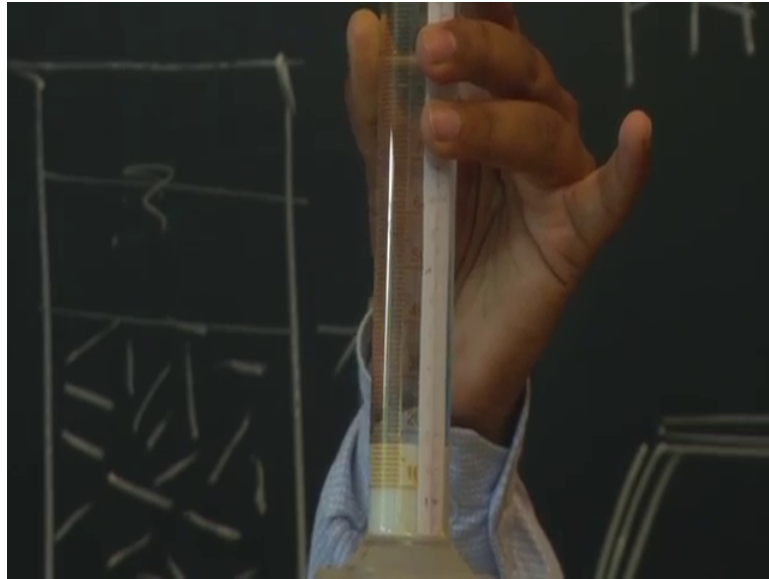
So, if kaolinite is mixed with kerosene in a cylinder, the platelets would arrange themselves in this manner and edge to face interaction they have and the particle or equilibrium volume is higher, because here the particles would not interact with the fluid. So, therefore, the volume is higher.

However, if the distilled water is used in place of kerosene so, distilled water which has a pH higher than the isoelectric point of the edges, the charge of the edge would change to negative. So, therefore, now edges and particle face both have negative charge therefore, particles would arrange themselves into face to face manner.

So, therefore, in the same jar when water is mixed with, when kaolinite is mixed with water, the particles would arrange themselves into face to face manner. So, final sediment volume is smaller, this is the equilibrium sediment volume. Essentially the kaolinite and bentonite when there mixed with water the particle arrangement is face to face only, there in dispersed condition. However, in case of kaolinite because diffuse double layer does not exist around the clay platelet because low surface area and low CEC. So, the volume is smaller. In case of bentonite due to high surface charge, the diffuse double layer thickness is larger though volume is very high.

So, therefore, when it is compared with kerosene volume is much lower, when it appears that the. So, therefore, the volume is lower compacted state when kaolinite is in a compacted state when the structure is built on a kaolinite, it can take whatever the load that is put on the soil in dry state. But; however, when the soil is saturated the structure of the kaolinite would change to face to face arrangement and which causes collapse on the soil.

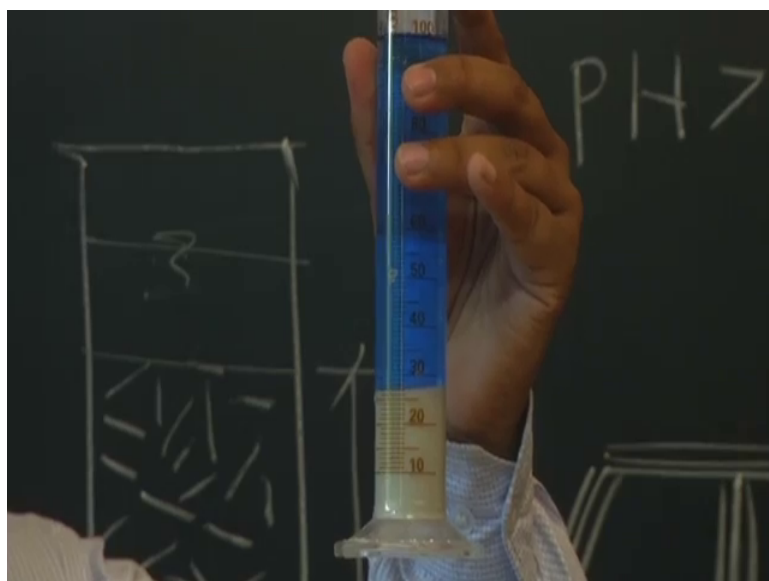
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Here the kaolinite is mixed with water and the kaolinite platelet us. Now they would disperse and finally, settle with time and at equilibrium this is the volume that exhibits that is exhibited by the kaolinite.

So, volume is about 18 ml in water. So, there is a clear solution that is formed and but as the P H value increases. So, there is a lot of dispersion that takes place and the clear solution may not be visible.

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So, in case of kerosene the volume is higher, the volume is about 28 ml, again the volume of the equilibrium sediment volume would vary with amount of kaolinite mineral that is present in kaolin soil and the surface properties.

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So, when the kaolinite is mixed with water. So, there is a dispersion that forms because particles are now arranged in face to face arrangement, face to face manner. So, it would take enormous time to settle and come to equilibrium.

So, when it comes to equilibrium there is a thickness of sediment volume would be much higher compared to kerosene or much higher compared to the sediment volume in the presence of kerosene. So, the dispersion still after formation on this equilibrium volume, there is some dispersion usually that is left above the clear solution (Refer Time: 23:29), the clear solution.

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So, this is the moisture sensor called EC 5 developed by decagon, which is a inexpensive sensor for measurement of moisture content in the field and laboratory. This determines the volumetric water content directly based on the dielectric property of the soil using capacitance principle. So, you can also obtain the dielectric properties of different fluids, if you immerse it in water based on the dielectric property it will give you the volumetric water content. And, if you put it in kerosene as the dielectric constituent is much smaller are significantly lower compared to water the volumetric content water also changes.

So, apart from this so, this can be directly embedded in soil in the field or in the laboratory columns to estimate the volumetric water content which changes in the moisture content.

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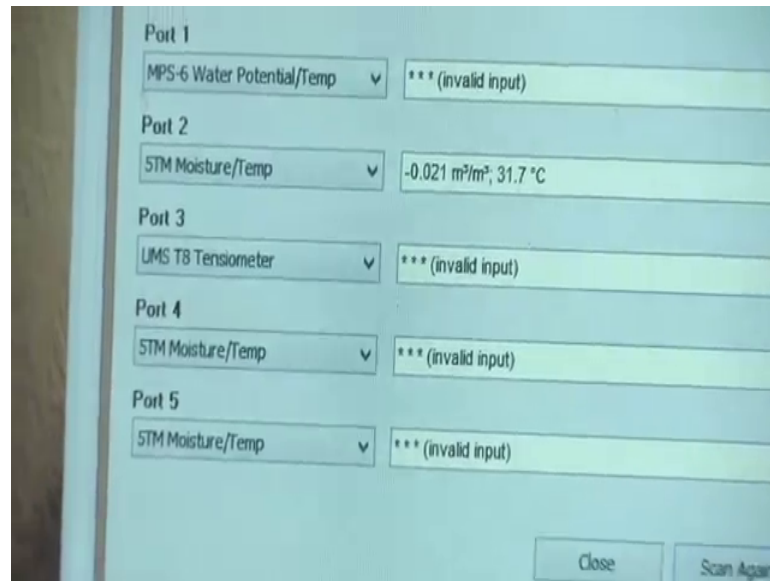
So, this is another moisture sensor called 5 TM which is also developed by decagon. So, these 2 sensors can be used in the soil for the estimation of volumetric water content. So, now, we will demonstrate how the sensors respond in the presence of water in the presence of a soil with different moisture contents.

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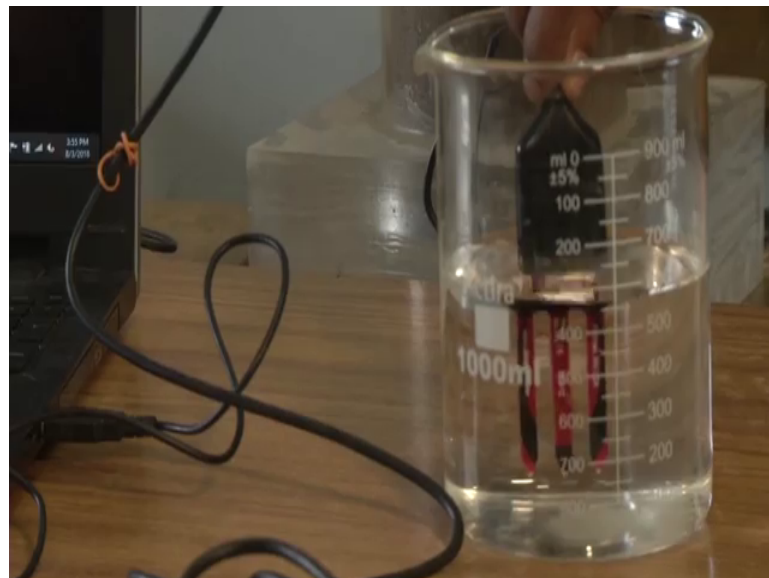
The 5 TM moisture sensor is connected to data logger called EM 50.

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Now, this is connected to the computer to read the data. The data logger can record and store the data for very long time. So, currently it shows the value is nearly close to 0. So, the volumetric water content is close to 0, which is volume of water by total volume. So, it is meter cube per meter cube. Now, the sensor will be dipped in water.

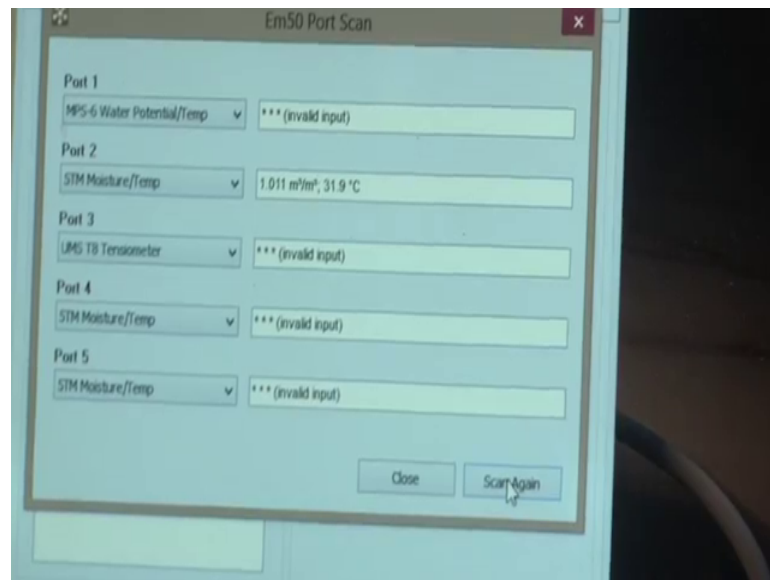
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Let us observe the change in the reading when the sensor is dipped.



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The reading change has to close to 1. So, which is validating the sensor is working or not. Now, this sensor will be dipped in soil and soil will be flooded and the moisture content will be changed within the soil so, that we can record the readings.

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Now, here the sensor will be embedded in the column, where sand is poured. Here the sand is poured at very loose density then the sensor will be embedded. Sensor will be directly kept in the soil, the orientation of the sensor could be in any direction, it could be horizontal or vertical, but; however, the orientation of the sensor is sensor should be

perpendicular to the soil axis. So, otherwise when there is a movement of water, that would influence the readings of the sensor.

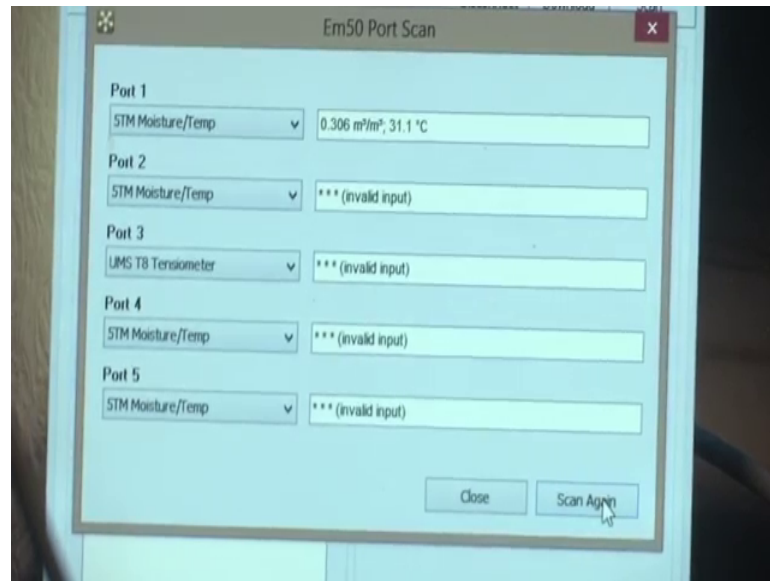
So, this whether us sensor can be embedded. This is now the sensor is embedded in soil, the sensor is connected to the data (Refer Time: 27:18) Now, we are set to go, now we connect this column with a water reservoir, when the water enters into the sand column, the changes in the moisture readings let us observe. Now, the column is connected to a water reservoir. So, that can be seen here when we allow the water to flow. So, water slowly enters into the sand.

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We can see the movement of water into the sand column. So, now, water rises in the sand column. So, the movement of water can be clearly seen. Now, water rises slowly and reaches the sensor, and as the water comes near to the sensor the readings of a volumetric water content will change. The sensors have very small radius of influence. So, when the water enters into that zone the volumetric water content will start changing.

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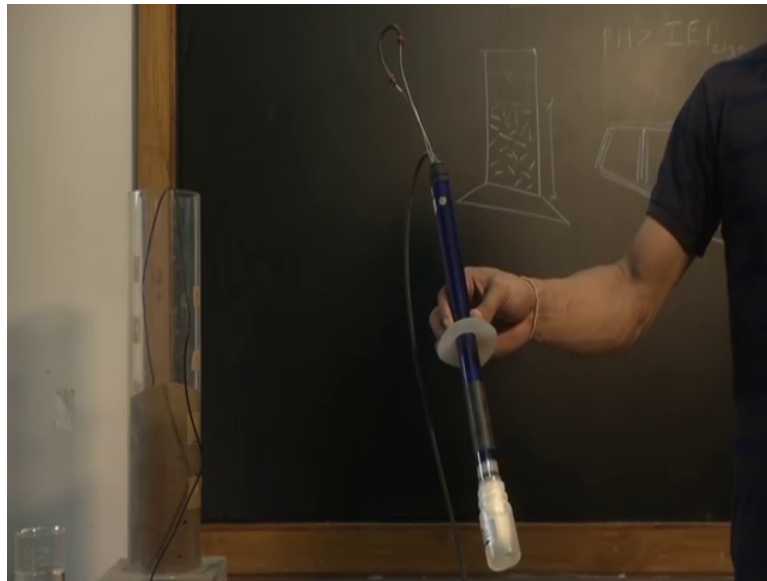


Now, you can see the changes in the water content, the volumetric water content is about 0.163 now. This will be continuously stored the data volumetric water content data will be continuously stored, but if you want to see it we need to scan it and then see at any given point what is the volumetric water content.

So, the value has change now 2.306. So, that will keep changing and at the end of test we can plot the changes in the volumetric water content with time, at the place where the sensor is embedded in the soil. We are not able to see in the sharp wetting front here because soil is compacted in a loose state and then the densities would slightly change and therefore, there are some fringes that appear here. So, the volumetric water content is nearly 3.346 to 0.516 now, the sharp variation in the colour can be seen in the soil. This movement of water also can be predicted, if the head is constant using green (Refer Time: 29:57) method provided the saturated water content of the sand is known and the initial head of the soil is known.

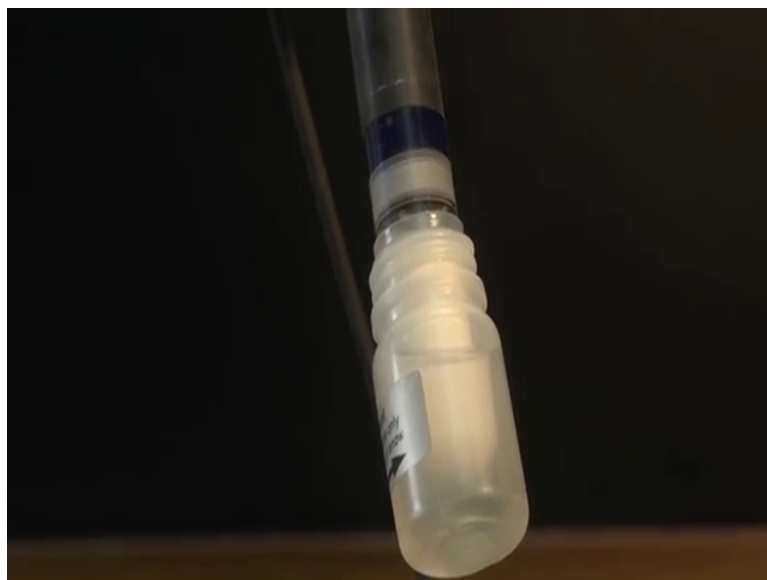
Now, theta value which is 2.356 slightly increased 2.36, because a head reduced now the hydraulic gradient is reduced. So, the movement is slower now. Here, we are not maintaining any constant head. So, therefore, this moisture sensor is very useful even in the field to determine the movement of water or the variation in the moisture content within the soil with time due to rainfall infiltration or any other conditions. So, that it can be used in wetting in use landslides problems.

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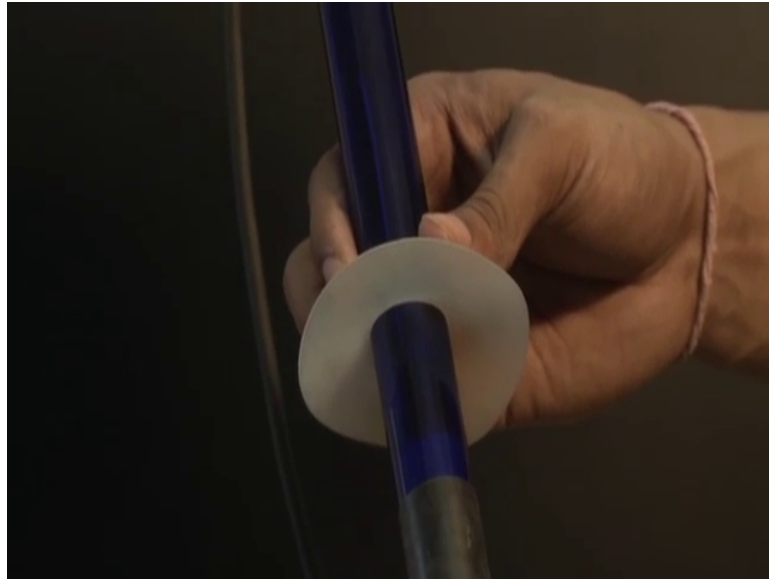
It is a T 8 tensio meter, the tensiometer generally the basic tensiometer has a higher intrinsic porous disk.

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Now, the tip can be shown this tip is immersed in distilled water. And, this higher intrinsic disk would not allow the air to enter into the system until the matric suction reaches the air entry pressure of the porous disk.

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So, now this is the whole system and which is connected to water reservoir inside.

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And, sensor to read the negative pressure which is transmitted to the porous disk, when it is connected to a soil column or when it is connected to a soil which contains negative water pressure.

So, this is the whole setup this is the T 8 tensiometer, the distill one which is developed by the (Refer Time: 31:57) again, which can be connected to a data logger and the

readings can be read. The tensiometer it can measure in the range of nearly 1 Kilopascal to 100 Kilopascal.

However, the cavitation would limit its measurement range to go beyond 100 kilopascal. Even there is an air entry of the higher entry disk allows it to use for more than 100 kilopascal. The cavitation pressure which is nearly the atmospheric pressure minus the vapour pressure, this value is smaller than 100 kilopascal which would limit the location of this tensiometer for measuring the suction value beyond 100 Kilopascal. Due to dissolved soils etcetera the range of this particular tensiometer will again decrease.

So, this tensiometer can be readily used in the field along with moisture sensors for establishing soil water characteristic, curve have to observe the changes in the suction with time. However, the response time of the tensiometer is different from the response time of the moisture sensors. Moisture sensors respond quickly compared to tensiometers. So, this tensiometer's response time varies with the initial condition of the tensiometer and the moisture content in the soil. So, the hydraulic equilibrium when it has to establish the hydraulic equilibrium time would be equivalent to your response time. So, hydraulic equilibrium time would be higher in case of expansive soils.

So, therefore, it takes several minutes to hours to get an equilibrium value on the other hand the moisture sensors reduce immediately. So, therefore, the caution should be followed to obtain equilibrium moisture content and equilibrium suction values in the laboratory, but in the from the field data when we read. The data will be not accurate or the data would not allow due to relate the moisture content and suction immediately because the response times are different.

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This is an mps 6 sensor which is developed by decagon. So, this is also to measure soil water potential or matrix suction in the field and laboratory. This can be embedded in soil just like the other moisture sensors. And, if you look at the size compared to the tensiometer of the size is very small. And, this is inexpensive and this can be readily used in the field. The range of suctions it can be measured would vary from 9 kilo Pascal lowest suction to maximum value of 1000 kilo Pascal. So, this is 100 MPa 100 mega Pascal's which is given by company.

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So, this has fixed matrix porous ceramic disks 2 disks which are placed of these disks are size of 36 7 and in between there is a printed circuit board.

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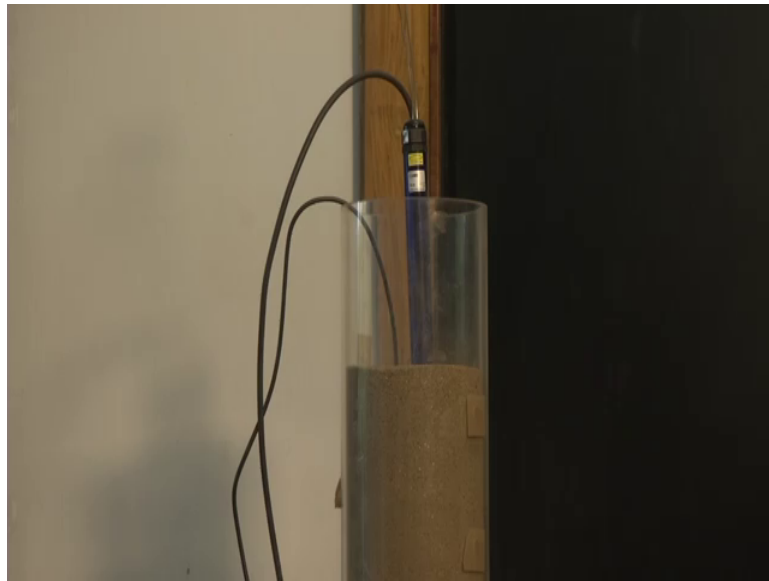
And, outside you will have stainless steel screens. Now, when this is embedded there is a hydraulic equilibrium between the sensor and the soil that takes place. The sensors are first of all very useful for estimating the matrix suction or soil water potentials, in highly expansive clays, because the suction range vary significantly for the soils.

However, recent studies by (Refer Time: 36:08) in 2016 show that the sensors would not respond correctly beyond 3000 kilo Pascal or 3 MPa, when it is compared the values are compared with WP 4 or hydrometer readings, because initially when the sensor is wet the moisture flows from the sensor to the soil. So, during that time the surrounding soil swells and the moisture flow stops. So, because of that the readings are not accurate.

Some other hand when the when the sensor is initially dry, but the soil is wet then the moisture movement takes place from the soil to the sensor soil volume decreases. Due to which there is a discontinuity with the soil due to which there are some measurement errors. So, even though this is a inexpensive sensor that could be used for measuring the matrix suction in the field, it has several limitations due to workability conditions in the field.



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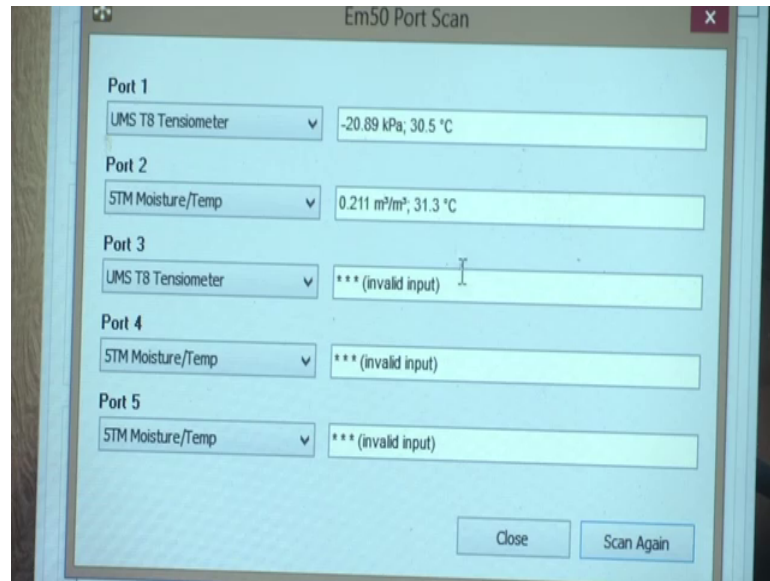
Now, we have kept moisture sensor and tensiometer in the column and we are filling sandy soil sand is filled to nearly top level. Now, this is level and now it is ready, now we will allow the water to flow through by connecting it to reservoir. So, now, this is connected to a reservoir.

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Now, water is going into the column due to the provided hydraulic gradient.

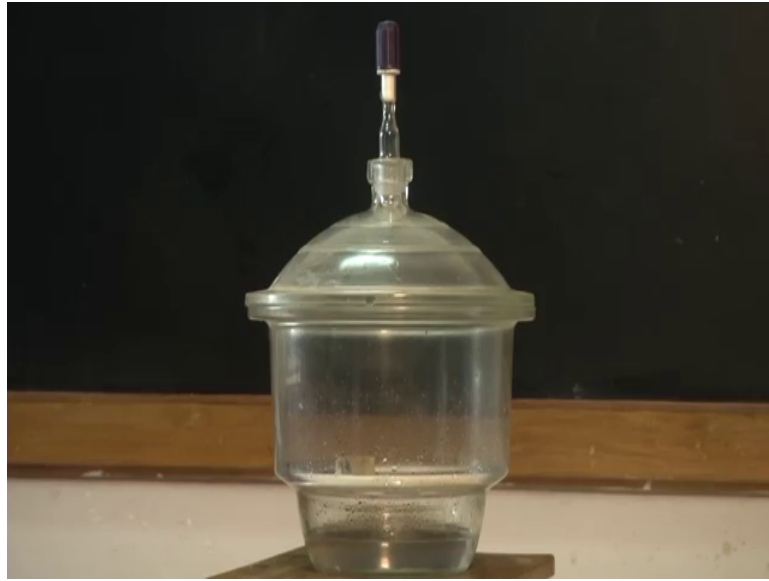
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Now, let us see how the readings change. So, the first port is connected to the tensiometer and second port is connected to 5 TM that can be seen here. So, the first port has the value of suction equal to minus 19 Kilopascal and the volumetric water is 0.057 meter cube per meter cube scan, as more water infiltrates, the readings change. Now, the new reading is 0.211 for the moisture sensor and suction is nearly seen 20.89. So, the response (Refer Time: 39:02) tensiometer is higher. So, therefore, the suction value is not changing, even though the water level is changing. So, the moisture content value is changing.

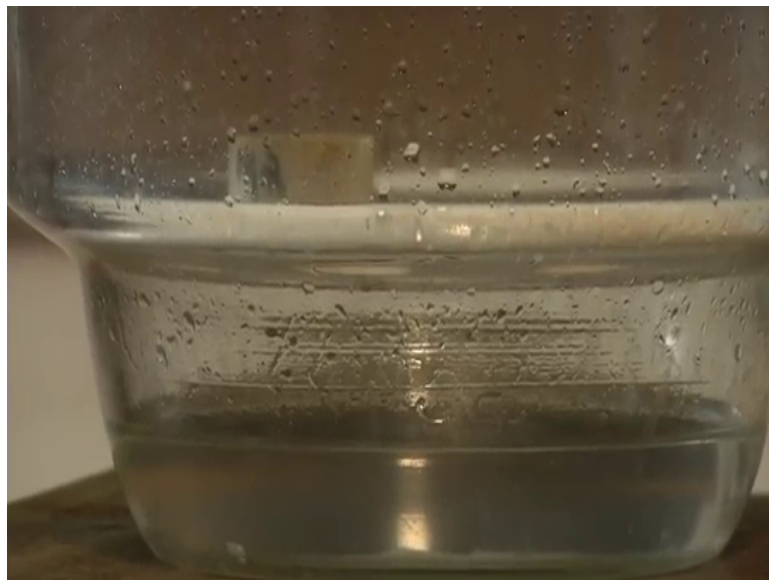
So, therefore, we cannot directly use moisture content and suction data to establish SWCC from this method. The moisture content now changed to 0.315 and whether the tensiometer reading is 21.57 kilo Pascal. So, it can be seen that the response times for these 2 cells are different.

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And, it is a vapor (Refer Time: 39:44) technique where soil sample is kept in a closed desiccator.

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And, at the bottom the soil solution is placed in the we can clearly see the soil sample, which is kept above the soil solution. However, the vapors from the soil solution interact with the soil and depending on the vapour pressure of the soil solution, either moisture will be taken from the soil or moisture will be absorbed by the soil. Finally, after equilibrium the vapour pressure of the soil pore water will be same as the vapor pressure

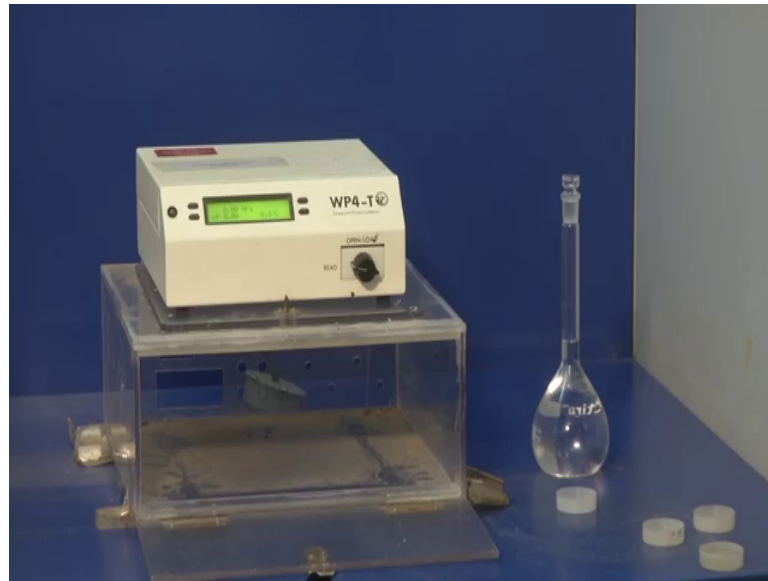
of the soil solution. We can place different soil solution at the soil solutions at the bottom with different concentrations. So, therefore, they exert different vapor pressures on the soil sample.

So, the vapour pressures of the soil solutions can be determined using WP 4 where the solution can be kept in double P 4 and directly the total suction value can be determined. Based on the relative humidity measurement from the WP 4, the total suction will be obtained. And, when this suction or the vapor pressure is in equilibrium with the soil pore water, soil also will have the same suction at equilibrium. So, use a different pore fluids at the different equilibrium territorial, whatever the water content soil achieves at equilibrium time one can establish the soil water characteristic on the drier side.

So, this is a useful technique. However, it is highly time taking, but this could be the only alternative in laboratory for estimating the soil water characteristic curve on the dry sides. This technique is very useful to estimate the, to control the suctions, to a high values, as high as 300 mega Pascal's. The technique is simple, but regularly need to monitor the weight of the soil sample. Once the weight of the soil sample is constant; that means, there is an equilibrium that is established between the soil solution and in the sample.

So, when the soil sample moisture content can be obtained at particular level. And, soil solution vapor pressure can be obtained from the WP 4 technique, which gives the suction value within the soil sample and suction, and moisture content with these 2 values are known we obtain 1 beta point on the SWCC on the drier side.

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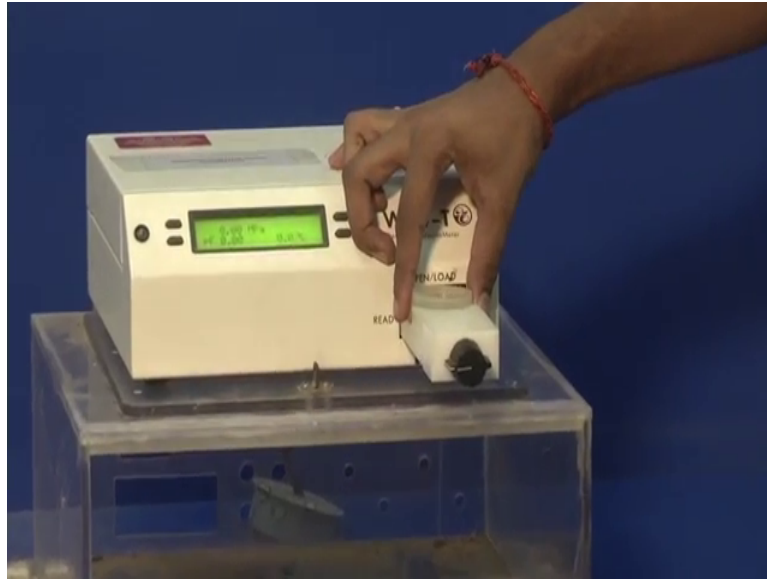


So, this is dew point potentiometer or WP 4 designed by decagon. This works based on the principle of measuring dew point due to condensation. Initially the soil may have particular vapor pressure, when the sample is kept inside this WP 4 instrument or equipment. There is a closed chamber where in our temperature controller, when the temperature is reduced drastically it reaches the vapor pressure becomes equal to the saturated vapor pressure at temperature point under that particular temperature, which makes the formation of dew point. So, that will be deducted.

So, as soon as it is deducted, it records the dew point temperature as well as initial temperature. Based on these 2 readings, it is possible to estimate the initial relative humidity of the soil pore system. So, from that using Kelvin's equation it is possible to determine the total suction of the soil.

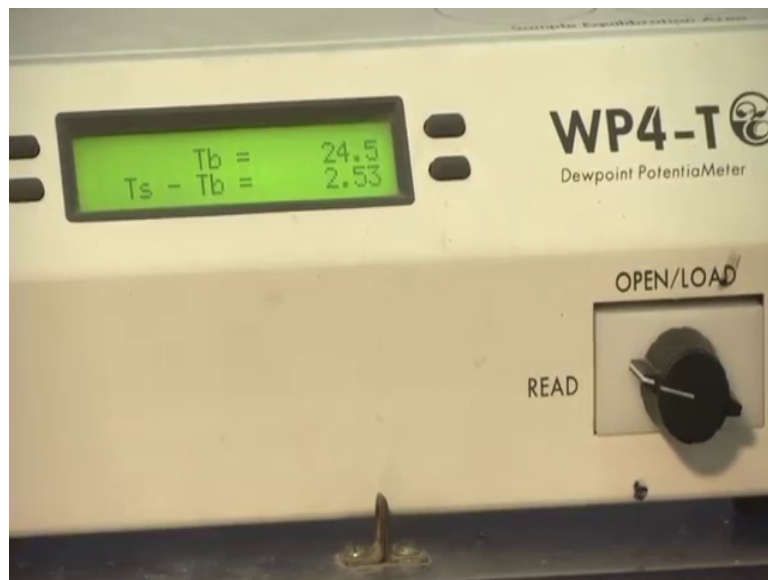
So, this can be calibrated using different soil solutions when a KCL solution is used with the concentration of 0.5 at temperature 20 it gives a total suction value of 2.184. And, same KCL when it is used at saturated solution that is 342 grams of solute should be added in one liter of water then it gives a suction value of 21.9.

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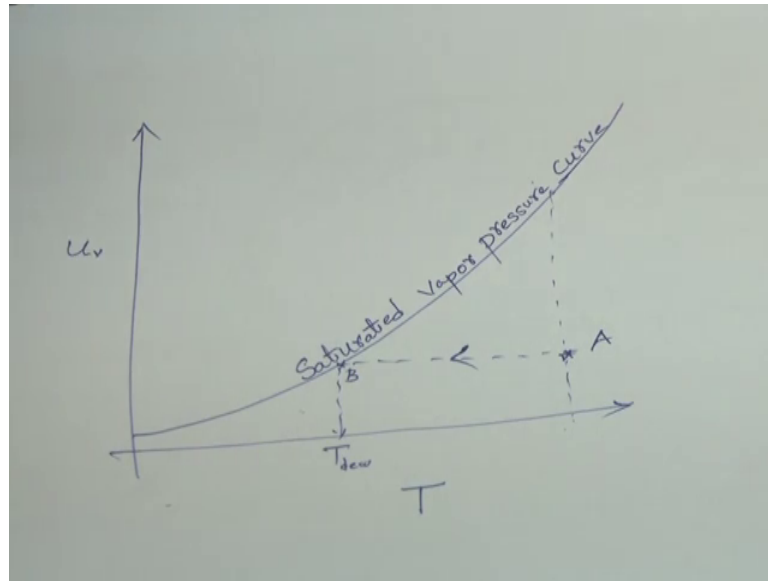
Then, the soil solution is taken and in the cup half full, then it is placed in this door and when you close it the solution when you put it on.

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Now, the temperatures will be gradually reduced inside then this vapor pressure wherever this is equal to the saturated with pressure, corresponding temperature is a dew point temperature. So, that reading it gives here KCL 1 molar solution is used. So, the corresponding suction value is 4.6 mega Pascal. Here we can see the changes in the temperature.

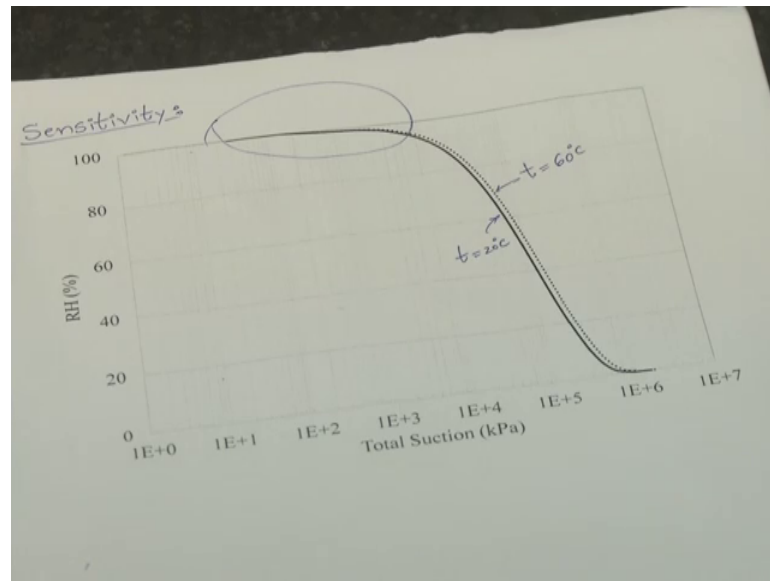
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So, this is the relationally between vapor pressure and temperature in Kelvin. So, this is the saturated vapor pressure curve. So, when the sample is kept in WP 4, initially the point a represents the sample condition, sample has particular temperature and corresponding vapor pressure. As the sample is kept inside the WP 4 chamber, the temperature is slowly dropped, and it follows this line, when the temperature is decreased it hits saturated vapor pressure curve. At 1 particular temperature which is called dew point at the particular temperature dew forms or condensation takes place. So, that will be deducted by this instrument.

So, when the dew point temperature is known and the initial temperature is known, from this, from the available formula for saturated vapor pressure knowing the temperature one can estimate the saturated vapor pressure, this vapor pressure is actually (Refer Time: 46:15) to the initial vapor pressure of the sample. And, corresponding saturated vapor pressure for that initial temperature will be obtained. From knowing the vapor pressure at the initial point and corresponding saturated pressure on to the same temperature. One can estimate the relative humidity and from that the total suction will be obtained and that is what is reported by this instrument.

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So, this is the relationship between relative humidity and total suction from Kelvin's equation. So, here the sensitivity of the Kelvin's equation is given and for different temperatures the solid line is for temperature 20 degrees Celsius and the broken line is for 60 degree Celsius. So, as you can see at relative humidity values of close to 95 or so this is highly insensitive. For the variation of total suction from nearly 10 kilo Pascal to around more than 1000 kilo Pascal the variation relative humidity is negligible.

So, therefore, when the relative humidity is close to 100 percent nearly above 95 or so, the values obtained from this particular technique is there only as or not accurate. So, on that higher side of the suction this method is very useful, because the sensitivity is very good and the variation in the total suction with relative humidity are very sensitive. Therefore, this particular technique can be used for the range perhaps more than 2300 kilo Pascal to even upto 100 MPa 100 1000 kilo Pascal.

So, now the difference between sample temperature and box temperature is nearly close to 0, after reaching minus 0.07 the difference between  $T_s$  and  $T_b$ . So, now, the once you load it will display the measurement of suction, after sometime it displays the reading. The so, total suction value is 2.1 mega Pascal, now it started displaying the reading and it will change, the current temperature of the sample is 24.3 degree Celsius. At equilibrium it will show 4.6 mega Pascal for 1 molar KCO solution. Still it is showing the temperature variation in the sample temperature and the box temperature, when the



temperature difference becomes negligible or close to 0, then dew formation takes place and it indicates the total suction value or it gives the total suction value.

Similarly, the soil sample will be loaded which is filled in the same CP half full. And, again it has to come to equilibrium with the chamber. And, once the temperature comes to equilibrium once the condensation occurs dew point forms, and the corresponding vapor pressure will be recorded, and based from that the relative humidity will be estimated using the Kelvin's equation the total suction will be displayed here.

Similarly for different soils at different moisture contents total suction values can be obtained using this particular technique. Here the total suction can be obtained and the earlier technique using equilibrium technique we were controlling the total suction. Here total suction can be estimated for a known moisture content.