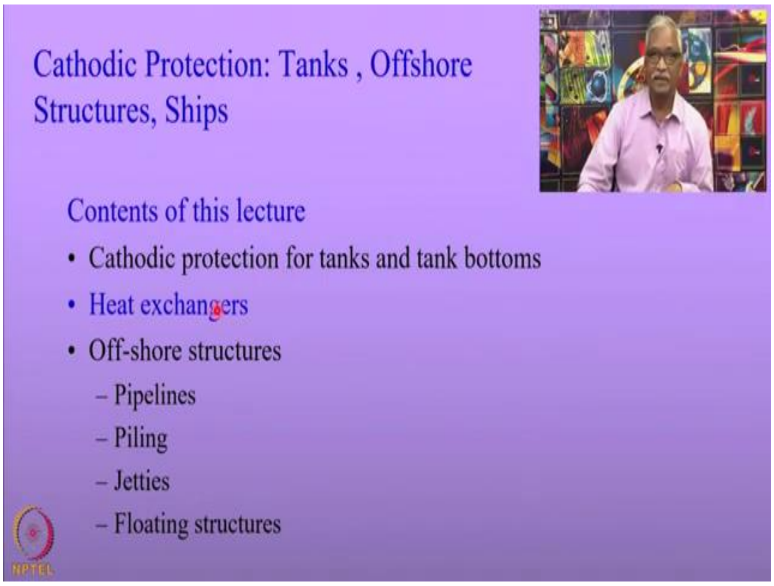
Cathodic Protection Engineering
Prof. V. S. Raja
Department of Metallurgical Engineering and Materials Science
Indian Institute of Technology, Bombay

Lecture – 08
Cathodic protection engineering: Perspectives in storage tanks and off-shore structures

Welcome to this course on Cathodic Protection Engineering. So far we have seen that the cathodic protection engineering involves two basic concepts; first the electro chemical corrosion and second the electrical engineering. When you talk about maintaining the potential of its structures with respect to the soil, and the relation between that potential and the current; the electrochemistry is involved.

However, the current that flows in the soil and as well as in the structure are governed by the electrical engineering concepts. These we have seen mostly as applicable to the pipeline structures; the governing resistance of the anode ground bed, the criteria for cathodic protection and even the various forms of corrosion, the buried structures face in the soil, we all seen earlier in detail.

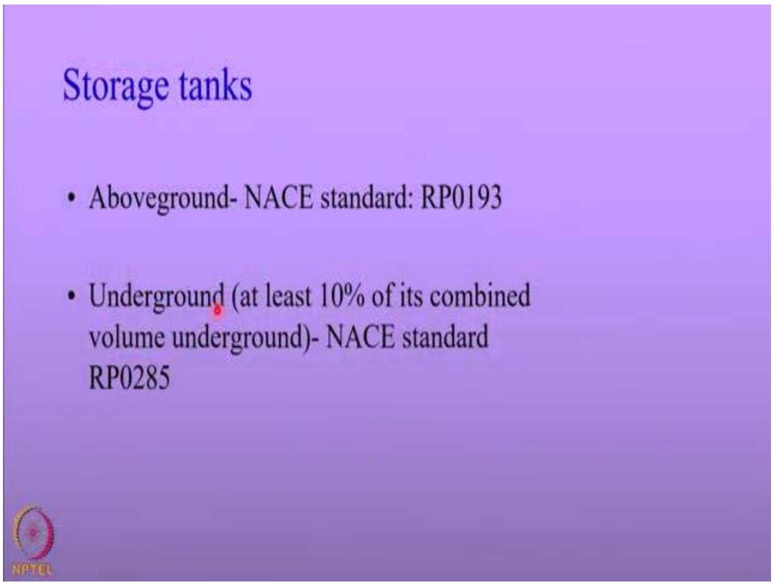
(Refer Slide Time: 01:26)



Today in lecture, we will be talking about the cathodic protection of tanks offshore structures and the ships. If you look at that, the major principles as applied to the pipelines are very similar. And so, we are not going to talk about in detail all the electro chemical corrosion concepts or the calculation of resistivity of the anodes in the soil, all this we are not going to discuss today; what we will be discussing today, will be very specific aspects as applicable to tanks offshore structures and ships.

In today's lecture would have the following content; we will start with discussing the cathodic protection of tanks and tank bottoms and then we will move on to the heat exchangers, very small discussion on the heat exchangers. And then we will discuss again in briefly the offshore structures that involve pipelines, piling, jetties and floating structures. So, let us start our discussion straight into the tanks.

(Refer Slide Time: 02:43)

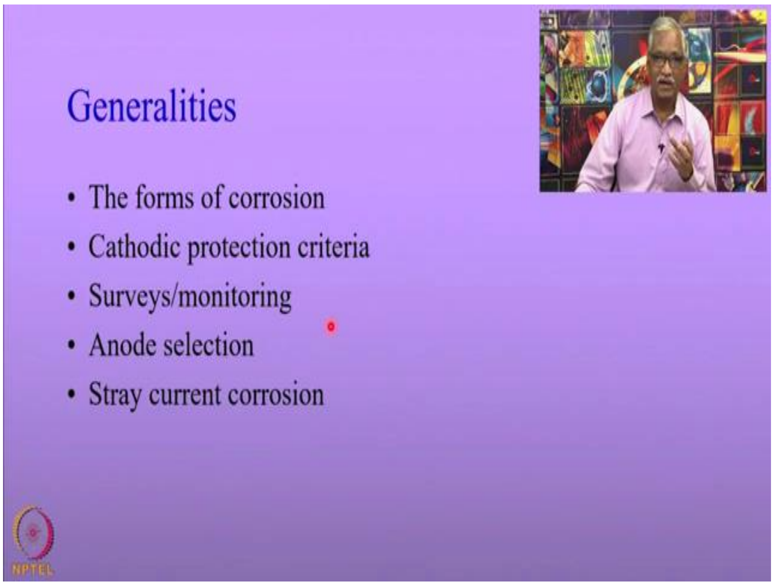


The storage tanks if you look at it, next only comes to the pipelines in terms of the extent of cathodic protection applied to the structures. So, let us look at now the cathodic protection of storage tanks; the storage tanks are classified into two categories, above ground storage tanks and those which lie underground.

These two storage tanks governed by two kind of NACE standards, which is RP 0193 and the RP 0285 for the underground storage tanks. The nitty gritty details of the cathodic protection as applicable to these tanks can be seen in these standards.

What we will be looking at here is the general principles, the concepts behind the cathodic protection of these two types of storage tanks. At the outset we need to distinguish between what makes the underground tank different from the above ground tank in terms of the definition. Those tanks which are buried at least about 10 percent of its combined volume in the underground is called as the underground storage tanks.

(Refer Slide Time: 04:05)

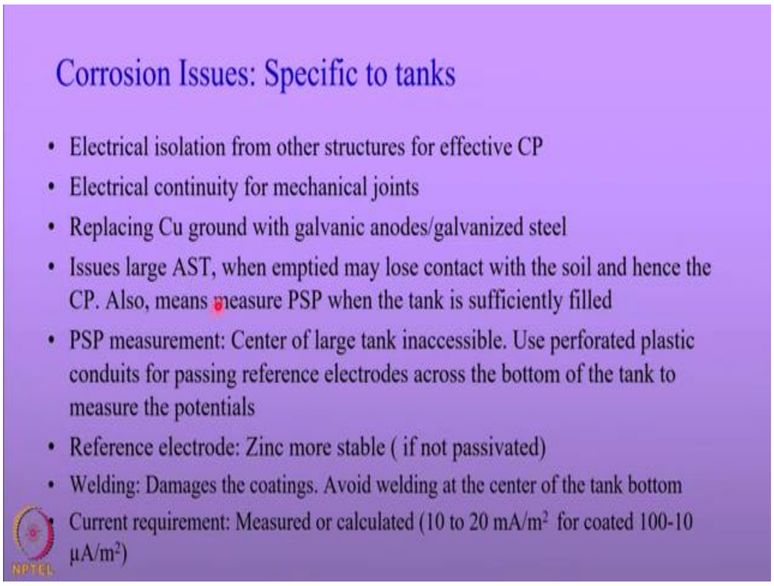


Let us look at the generalities that are involved in the storage tanks. The storage tanks mostly are buried in the soil, be it above ground storage tanks or underground storage tanks, they are exposed to soils mostly. And so, whatever you discussed in relation to the pipelines which are buried in the soil in terms of the forms of corrosion that you see here; like what types of corrosion like the bacterial corrosion, the differential aeration corrosion, all these are applicable to the storage tanks as well.

The cathodic protection criteria as applicable to the pipelines are as well applicable to the storage tanks. The surveys in relation to soil resistivity, pipe to soil, the current requirement, even this stray current corrosion are all applicable to the storage tanks. The anode selection criteria, the way you calculate the ground resistance is very much similar to the way you do it for the pipelines.

The storage tanks are also suffering from stray current corrosion; because there are current that strays from the anodes of the cathodic protection systems to other structures and then return back to the storage tanks. So, they also suffer stray current corrosion. So, these are generalities, which we will not be discussing in this lecture.

(Refer Slide Time: 05:45)



Let us look at the specific issues that are applicable or one should be worried about when you talk about the storage tanks. The storage tanks we know, there are some process liquids which are being stored or been taken out.

So, there are inlets and outlet pipelines and these pipelines required to be electrical isolated or if you cannot isolate them; we need to look at as a composite structure, when you design the cathodic protection systems. When you have again the tanks, the tanks would have mechanical joints and this one; it is necessary that one ensures that these mechanical joints are electrically continuous, so that the current will flow into the structures.

The storage tanks are earthed using copper; but whenever you go for cathodic protection systems, they are replaced with the galvanic anodes or the galvanized steels. There are special issues associated with the above ground storage tanks, especially because when you empty this tank; the contact between the soil and the tank bottom is getting loosened and thereby it is hard to measure the tank to the soil potentials.

So, the tank to soil potentials, we generally called also as pipe to soil potential is the one measured only when the tank is completely filled up. There is one more issue that is problematic to the tanks; that is how to measure the structure to soil potentials ok, especially the inaccessible areas, you would notice that there are tanks which are of very large diameters of few meter diameter the tanks; in which case, the reference electrodes cannot be access the bottom of the tanks.

So, the measuring potentials of the structure towards the center of the bottom of the tank is always a difficult issue, ok. So, in order to do this what is done is, people use perforated plastic conduits through which the reference electrodes are pass across the bottom of the tank to measure the potentials.

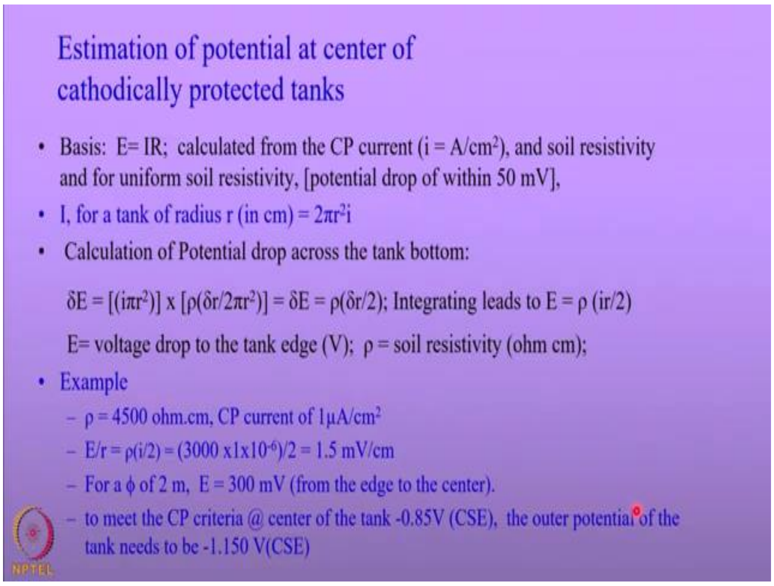
It is also possible to use zinc electrodes, because zinc electrodes is just buried in the soil. The normal reference electrodes like copper copper sulphate or silver silver chloride these reference electrodes, they have the solutions, they dry up over a time period.

So, these electrodes they become damaged, they do not show the values. And so, there is a need to change these reference electrodes with respect to time, which is not possible in the case of the tank bottoms. So, in order to do this, the zinc electrodes can be used, because zinc electrodes are buried in the soil; the only condition is that, zinc should not be passivated, the zinc sometimes get passivated, if you have carbonates in the soil.

The other issue that is specific to tank is during the commissioning of the tank and one should avoid welding at the center of the bottom of the tank. But that is easier said than done; when you are welding them, then the coating is damaged, then the current requirement to protect the tank at that location becomes very very high. Similar to the pipelines, the current requirements for the storage tanks to protect cathodically can be either measured or calculated.

Generally, the current requirement for protecting the storage tanks lies in the range of 10 to 20 milliampere per meter square for bare tanks. For the coated tanks, the current can be significantly reduced to 100 to 10 microamperes per meter square.

(Refer Slide Time: 10:21)



It is also possible, we have seen that measuring the potential of the tank with respect to soil is very intricate. Especially at the center of the tank, it is very difficult to measure the potential of the tank with respect to soil; because the reference electrode cannot be accessed.

The only way it can be done as we seen before is by using the perforated plastic conduits through which the reference electrodes are sent. However, it is also possible to estimate the potential of the structure with respect to soil at the center of a cathodical protected tanks. And that is done by using a simple equation that is Ohms law; let me just take this pointer here.

So, the calculation of the potential at a given location is based on simple Ohms law

$$E = IR$$

And we can get this E value provided that, you can able to calculate the current that is required for protecting the structure and the resistance offered by the soil between the two locations, right.

Now, we have seen earlier that, the current density required for protecting the structures can be either calculated can be measured; so that means the current density required for cathodic protection is known, the soil resistivity is known and we also assume that the soil is of uniform chemistry in nature.

And so, the soil resistivity across the bottom of the tank is quite uniform; in fact and when we lay down or when you commission the tanks, we normally spread you know the high resistivity soil, such as the sand here. We see below how one can calculate the potential of the tank at the center of at its center with respect to the soil.

First is to calculate the current required for cathodic protection, that is done by knowing the current density and then knowing the area of the tank. So, you know the total current required for the protecting the tank can be calculated. The next step is to calculate the potential drop across the tank, right. The potential drop across the tank delta E is given by the potential drop can be calculated based on this equation, which is pi r square which represent the total current and the rho delta r upon 2 pi r square.

If you solve this equation, it becomes delta E upon rho into delta r by 2, ok. If one integrates this potential drop with respect to the distance and you get here, which is which is the radius of the tank;

$$E = (\rho I) / 2$$

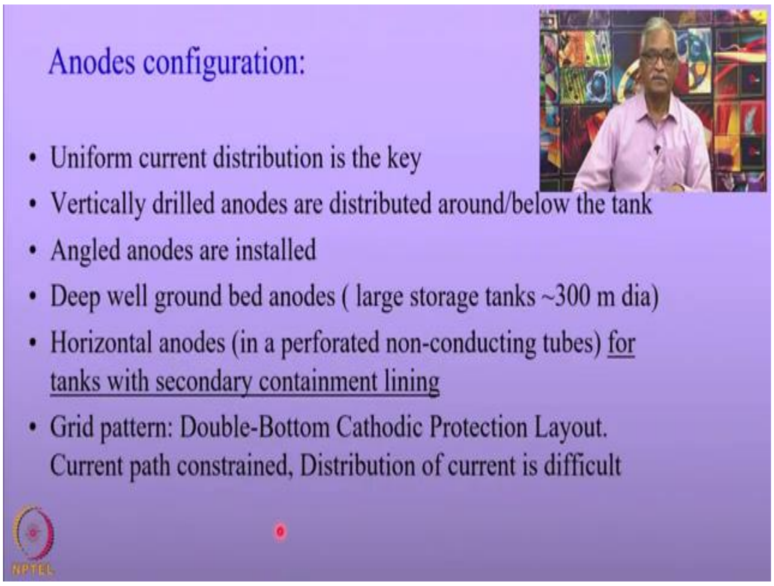
So, it is possible to calculate the potential of the tank at the center, if you know the potential of the tank at the edge.

In example is given below; to illustrate this point, the following calculations are being done. Let us consider a case where the soil resistivity is 3000 ohms centimeter and the current required for cathodic protection is 1 micro Ampere per centimeter square. Substituting these values in this equation; it turns out that, the potential drop across 1 centimeter is 1.5 millivolt, right. And for a tank of 4 meter diameter, the voltage drop from the edge to center turns out to be 300 millivolt, right.

So, let us look at the criteria for cathodic protection. We all know that, the minimum potential required for cathodic protection is minus 0.85 volt with respect to copper sulfate electrode for example. Then if you have to have a potential of minus 0.85 at the center; the edge of the tank should measure a potential of minus 1.1 volt with respect to saturated copper saturated copper sulfate electrode.

So, it is possible to calculate the potential of the tank at the center with respect to soil; if we know the resistivity of the soil and the current density that required for cathodic protection.

(Refer Slide Time: 15:30)



The other important requirement for the cathodic protection of the tanks are the ground bed. The resistance offered by the ground bed can be calculated as per the equation that you saw before; that is we in one of the lectures, we talk about the anode ground resistance calculations, right.

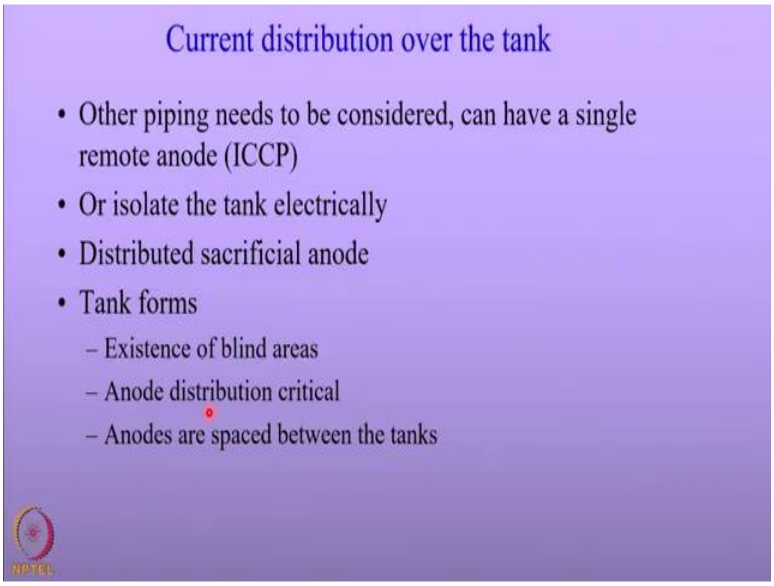
So, same can be used here to calculate the resistance offered by the ground bed. So, what we look at here is, what is important is; how the current is uniformly distributed in the tank, ok. Sometimes you may have several tanks around actually, ok. So, how the current is uniformly distributed; it depends upon the symmetry, symmetry with which these anodes are distributed.

You can also have a vertically drilled anodes can be distributed around the tanks actually; in order that the current is uniformly distributed or you can also have the angle anodes, which gives you even better distribution of the current. Where we cannot have distributed anodes; we can also have deep well ground bed anodes installed for large storage tanks of let us say 300 meter diameter the big tank and we can have a deep well ground bed anodes.

We know that the current distribution is much much larger; it is easy to maintain remote anode much easier with deep well ground bed anodes. The horizontal anodes are also kept, where it is not possible to have deep well ground bed anodes and for tanks with secondary containing containment linings; it can be possible to do that, ok.

And deep grid patterns; the anodes of grid patterns are also used where double bottom cathodic protection layout are required. And only problem here is the current paths are constrained; so the current distribution is very difficult.

(Refer Slide Time: 17:50)

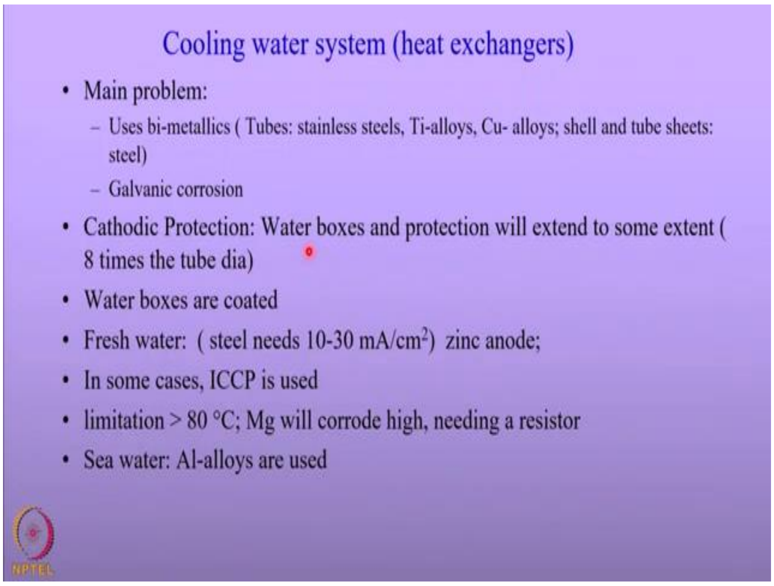


We talked about current distribution at the bottom of the tank; the current distribution at the core or the tank also equally important. In this case, the other pipings need to be considered; you can have; you can have a remote anode, so that the current distribution becomes quite easier or isolate the tank electrically for example.

And in the in the first case, you can have a remote anode, wherein you can also talk about other piping’s which are connected to the tank is done. We have seen the current distribution for the bottom of the tanks; the current distribution over the tank is also equally important. There are cases where the other piping’s are the considered, especially when the tanks are buried tanks and where the piping’s are part of the tanking process.

You can have a single remote anode that will take care of completely the cathodic protection of the tanks and so on, or it is possible to isolate the tank electrically and confine the cathodic protection only to the tank. You can also have distributed sacrificial anodes, ok. And there are tank forms; there are multiple tanks are present, in which case you can have a distributed anodes even between the anodes, you can have the tanks in, we can have the anodes installed, so that the current is evenly distributed.

(Refer Slide Time: 19:59)



The whole idea here is the current distribution has to be uniform and so the configuration of the anodes are accordingly done. Just move on to the next topic which is the cooling water system, wherein heat exchangers are used and these heat exchangers are required to be cathodically protected.

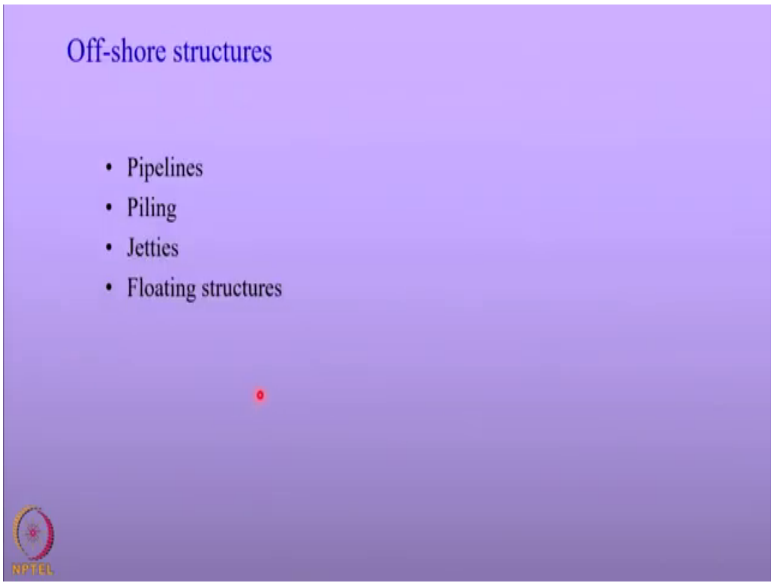
The main problem in the case of cooling water system is, in the cooling water systems, the heat exchangers they use bi metallic. And tubes are mainly consisted of stainless steels, titanium alloys and copper alloys, where the shell and the tube sheets are made up of steels and therefore, the galvanic corrosion occurs.

In order to prevent the galvanic corrosion, the cathodic protection is done. And the cathodic protection is generally done in the water boxes and the protection will extend into the tubes; the extent of about 8 times the tube diameter.

So, the galvanic corrosion in that location is significantly reduced, because of the cathodic protection that is offered for the water boxes. The water boxes are generally coated and for fresh water, the current required for cathodic protection lies in the range of 10 to 30 milliampere per centimeter square and zinc anodes are generally used. However, if the temperature is higher, goes beyond 80 degree Celsius and zinc anodes cannot be used and magnesium needs to be used in this case.

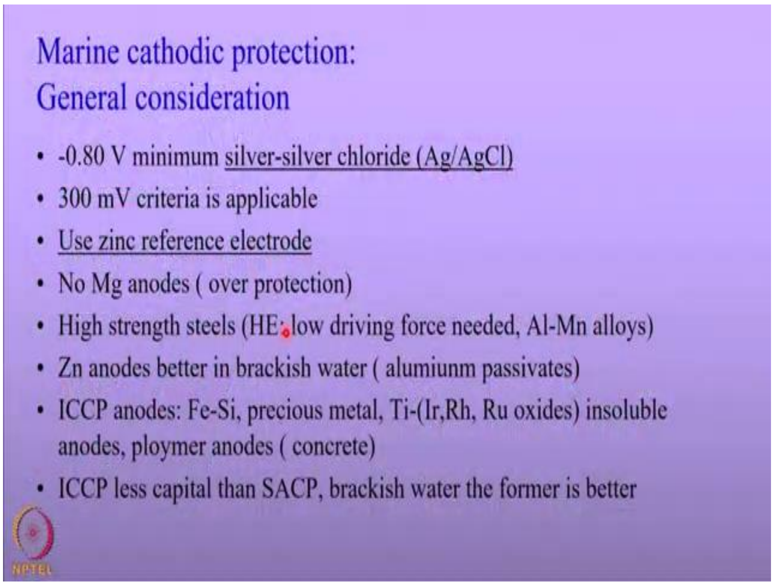
But if magnesium is used, it corrodes very high and offers over protection; needing a resistor to control the current delivered for protection of the structures. Whereas, in the case of aluminum in, whereas in the case of sea water; the aluminum alloys are used. The heat exchangers sometimes use the impress current cathodic protection system as well; but however, it is better to use sacrificial anode systems, because it makes it more easier to maintain.

(Refer Slide Time: 22:11)



Let us look at the offshore structures. The offshore structures that we discussed today are pipelines, pilings, jetties, and floating structures, ok.

(Refer Slide Time: 22:28)



And the marine cathodic protection as you put all of them; the general considerations are you have a cathodic protection criteria, which is minus 0.8 Volts with respect to silver-silver chloride electrode. Because the marine environment is more of chlorides; the copper saturated copper sulfate electrode is seldom used, rather they use silver-silver chloride electrode.

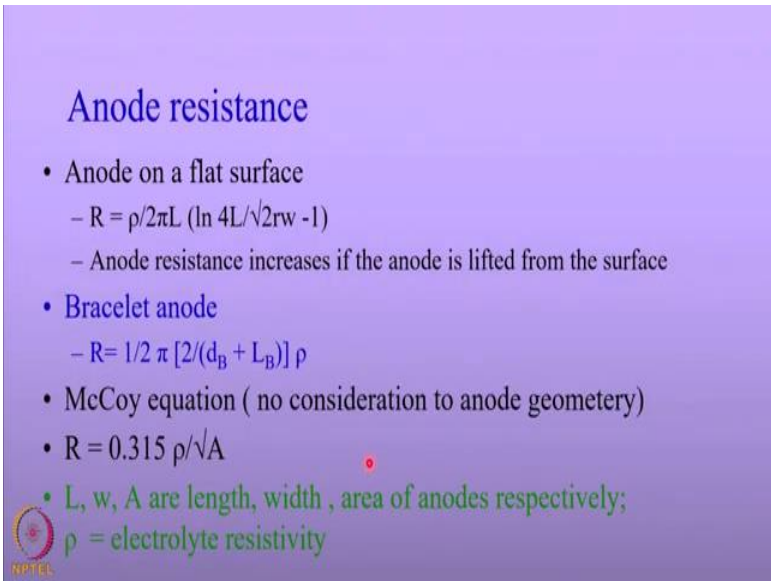
And so, the potential against it is minus 0.8 Volts, that is a criteria for cathodic protection. You can also use 300 milli Volt criteria, because the electrolyte is highly conducting. So, the IR drop in the electrolyte is not very high. However, this does not take into consideration, the resistance offered within the metallic structures.

Use of zinc reference electrode is very common; because zinc is less polarized anodically and so the potential does not change when it is used as a reference electrode. No magnesium anodes are used; because it will over protect the structures. What is important is, wherever you use high strength steels in the marine applications; since they are prone to hydrogen embrittlement, low driving force sacrificial anodes required to be used. One such anode is aluminum manganese anodes.

Zinc anodes are better in brackish water and as the aluminum passivates. For aluminum to act as a sacrificial anode**,** it is possible to have chlorides; when the chlorides are less, the aluminum anodes passivate. The marine structures both ICCP and the sacrificial anodes are used, systems are used. If there are ICCP is used, we have iron silicon, the precious metal such as platinum is used or titanium insoluble anodes or even polymer anodes are used, where you have concrete structures.

ICCP is less capital than sacrificial anode cathodic protection system for sea water applications; because you need to have large amount of sacrifice anodes installed. And for a brackish water, ICCPs works better than the sacrificial anode systems.

(Refer Slide Time: 25:11)

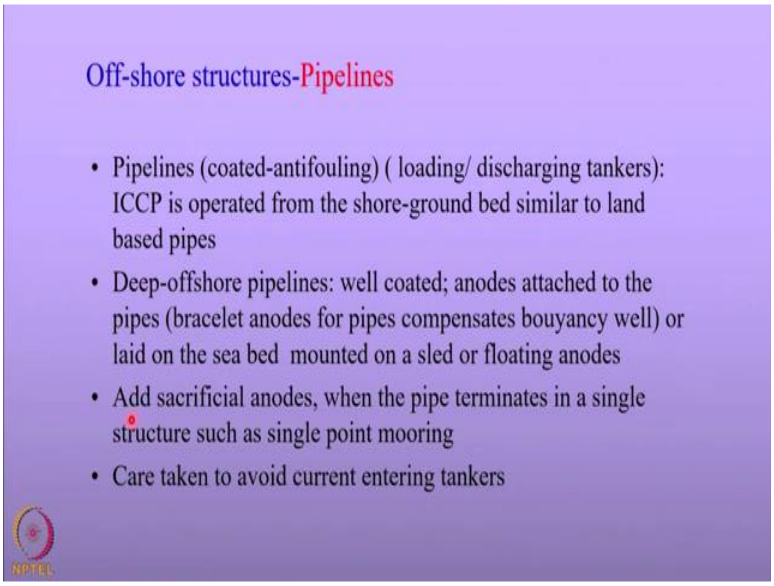


When I want to use the sacrifice sacrificial anodes or when we are going to use impress current anode systems, much the same way you do for soils; it is necessary to consider the anode resistance, the resistance offered by the anodes required to be seen. And these are the formulas that are being used they are; if you notice they are significantly different from what was used for calculating resistance of anode beds in the soil, ok.

And if you are going to use bracelet anodes, we talk about the diameter of the bracelet anode and the width of the bracelet anodes are used. You can see that, the equation to calculate resistance of the anode is changing depending upon the, this nature of the surface, flat surface and the curved surface with the bracelet anodes ok. And very simplified equations are many times used, this is called a McCoy equation; it does not take into consideration the anode geometry.

So, it is a very simple equations used to calculate the resistance offered by a given anode. All you need is the resistivity of the electrolyte, in this case the sea water may be and the area of the anode are used to calculate resistance offered by the anode. Just look at the offshore structures now in specific; just take the pipelines, the pipelines are coated with the anti-fouling coatings.

(Refer Slide Time: 26:54)



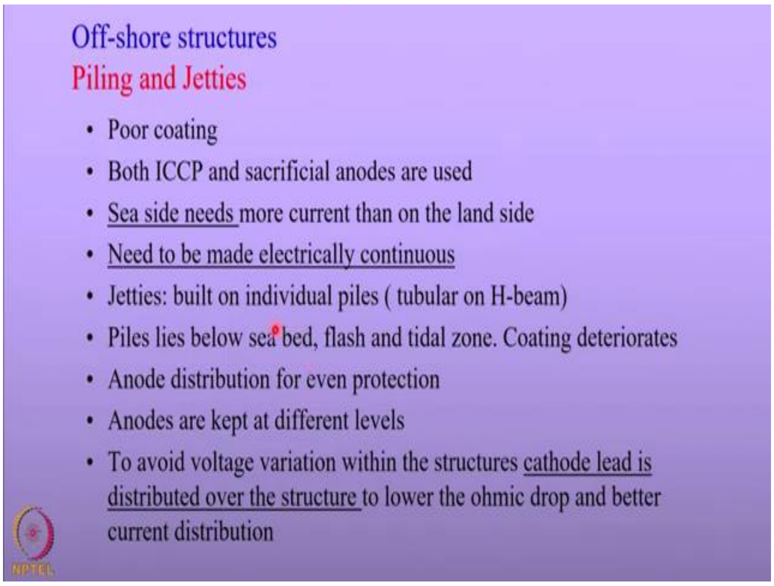
The offshore structures a lot of marine growths and in order to avoid the marine growth, anti fouling coatings are given. And this one thing very important when you talk about pipelines is, these pipelines are connected with the tankers for loading the, for loading the products may be crude or something like that actually or discharging to tanks, it can happen both the ways.

And if ICCP be operated in this case; if the ICCP is installed in the shore and that works better actually, ok. And for deep shore pipelines, the pipelines are well coated; because more you take care of coatings, less current is required for the cathodic protection systems.

The anodes again this case are attached to the pipes, which are generally as bracelet anodes; this also reduces the buoyancy of the pipeline, because adds to the weight of the pipeline or it is also laid in the sea bed on the seabed mounted on sledge or floating anodes.

The sacrificial anodes are added whenever the pipeline terminates in a single structure, such as single point moorings. Care needs to be taken to avoid current entering the tankers that could introduce stray current corrosion of the structures.

(Refer Slide Time: 28:57)



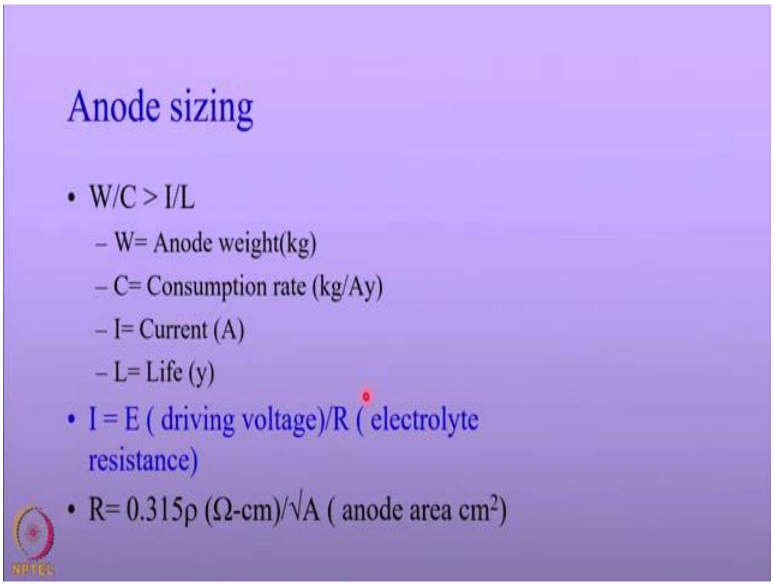
The offshore structures you also have piling and jetties, over here also you go for good coatings; poor coatings is a cause of concern. The one of the problems in the piling and jetties is that, when you have flash and tidal zones; the coating deteriorates because of continuous flashing of sea water actually, ok.

And again if you have structures on the offshore and on the stores connected, the one in the seaside requires more current than on the land sides, ok. And need to be made a little continuous; suppose you are protecting cathodically from the onshore, then the structure is to be electrically shorted in order that the current flows.

If you have structures in the offshores; the anodes need to be kept at different levels, so that the current is uniformly distributed in the structures, ok. So, that is anode distribution is very important for even distribution of current and so even protection of the structures. There are some corrosion occurring in the structures; the resistance, the structure can offer significant resistance for the flow of current.

And so, unlike the pipelines, that are normally buried in the ground; the cathode lead requires to be distributed, so that the ohmic drop within the leads are reduced and so that the current is better distributed.

(Refer Slide Time: 31:02)



Sizing of the anodes are very important when you talk about use of the sacrificial anodes. The anode weight you know; what is the weight required for cathodic protection is calculated based on these equations,

$$W/C > I/L$$

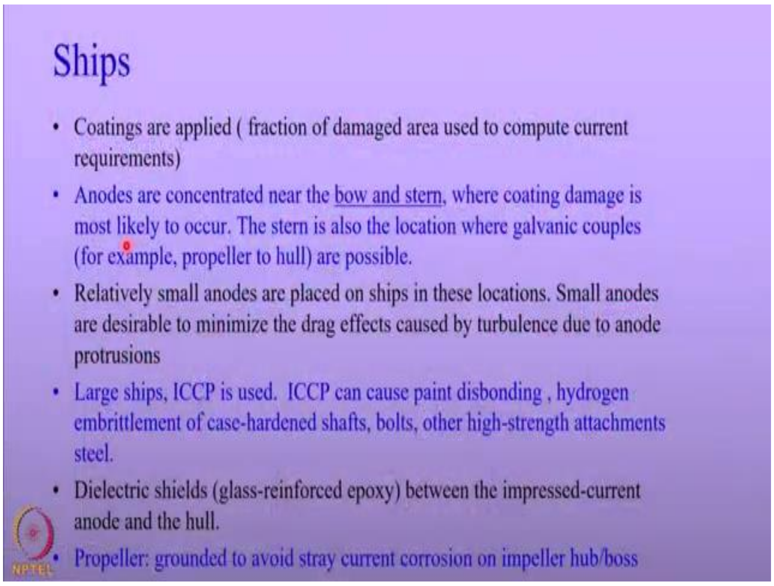
where W means the anode weight, the current consumption rate for given structures given in terms of kg per ampere year, ok. And the current required to protect the structures and the life of these structures that decides what should be the anode size in terms of the weight.

The anode size selection also depends upon the current that is required, there should be adequate driving voltage. We have seen this during the cathodic protection of pipelines, where the anode ground bed resistance were calculated; that is very much applicable over here also, that is the current that is required would be depending upon the resistance of the electrolyte.

And so, the driving force; the driving force of given anode is known and so it is necessary that R should be adjusted. How to adjust R, we have seen earlier right; there is relation between R on the area of the anode. So, it is possible that, if the area of the anode becomes smaller; you will not get sufficient current to protect the structures or the driving voltage is going to be reduced.

So, the sizing of the anode is based on the weight required to protect for the given life and as well as the driving force that is required to drive the required current for the structures.

(Refer Slide Time: 33:15)



Let us come to the last topic of today's lecture, we talk about the ships. So, again we are not go into details about the cathodic protection that is applied to ships; but what we look at here is the general concepts, overall approaches for the cathodic protection of ships.

As we all aware that coatings are applied onto the ships; but however, there are certain areas of the ships, where the coatings get damaged very readily. And so, the current requirement for protecting the ship would depend upon damaged area of the ship hull. So, the damaged area is used to compute the current requirement for protecting the ships. The anodes are concentrated more on the bow and the stern side, where the coating is damaged.

As you have seen before that, when the coating is damaged; the current recommend becomes more and so the anodes are more concentrated in these locations where the coating is likely to get damaged in service. It is also that the stern is also the location where the galvanic couples between the propeller and the hulls are possible. So, in order to reduce the galvanic corrosion between these two; the propeller is made up of relatively noble metal as compared to hull and so hull will suffer corrosion.

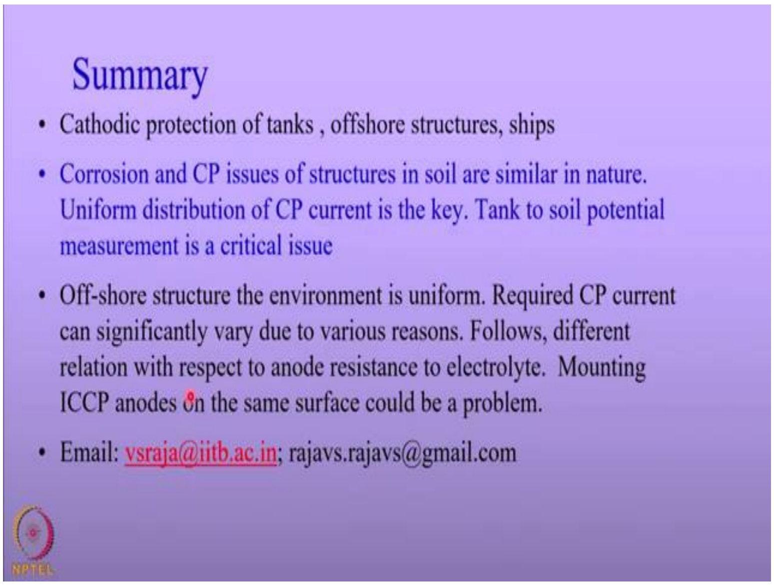
So, in order to control that, more galvanic anodes are located in these locations. The current distribution is very important and so small anodes are distributed, so that you know, so that the current is uniformly. The one more problem that happens at the above location is that, there is a drag associated with the anodes. So, the larger the anode, more will be the drag and so small anodes are distributed in order to reduce the drag onto the ships.

The ship size are becoming larger; using simply the sacrificial anode, cathodic protection system is unviable and so the ICCP is used, in fact ICCP and cathodic protections are used together in most of the ships. The one problem with ICCP is that, it can cause paint disbonding, it can cause hydrogen embrittlement of case hardened shafts, bolts, and other high strength attachments to the steels.

The one of the problems in using ICCP for ship hull is that, these anodes are mounted on the ship hull. So, this should be electrically isolated; otherwise the ship hull will become effective anodes for passing current and so they will suffer a huge corrosion. So, in order to give, in order to separate; so in order to separate the impressed current anodes, the dielectric shields are used. These dielectric shields generally or glass-reinforced epoxies and that separates the anode on the ship hulls.

And it is also known that, the propeller you know is to be grounded; otherwise the current will stay from the propeller into the ship leading to the stray current corrosion of occurring on the impeller hub bosses. So, propellers need to be grounded in order to avoid stray current corrosion in the ships.

(Refer Slide Time: 37:45)



So, we have come to the end of this lectures; before I close this lecture, I wanted to summarize what you have seen today. Cathodic protection of tanks, offshore structures, ships is what we saw today.

And we also saw that in the terms of structures, in terms of the tanks; the corrosion behavior of the tanks exposed to soil are very much similar to those the pipelines which are buried in the soil. And the corrosion issues, uniform distribution of cathodic protection current is the key for effective protection of tanks against corrosion.

And one issue that is very specific to the tanks is measuring the soil potential at the center of the tank is a problematic one. We also seen how to work on the problem; either we use perforated plastic conduits through which the reference electrodes are sent or it is possible to calculate the potential of the tank at the center, if you know the resistivity of the soil and the current density required for cathodic Protection and the measured value of the tank to soil potential at the edge.

The offshore structure environment as opposed to the soil is quite uniform and required current is significantly higher and it can also vary significantly; because if there is a tidal or if the ship moves for example, the current requirement becomes larger. Mounting ICCP anodes on the ship is another problem; because if the dielectric shield breaks down, then the ship hull can suffer severe corrosion.