Modeling of Cathodic Protecion for pipe lines

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Abstract

Corrosion is an international problem with more structures and materials buried in the soil. The most common and applicable technique to overcome this problem is cathodic protection.

In this work a Carbone steel pipe of length 100 cm is buried in a wooden box submerged by soil and Impressed Current Cathodic Protection system was applied using power supply and close circuit, several important factors has been studied, like Anode position (distance and depth), soil resistivity (wet and dry), condition the pipe (coated and un-coated), distribution of potential and currents along the pipe (cathode), the amount of current required to achieve cathodic protection. A mathematical model was developed to simulate the ranges of parameters and factors affecting Impressed Current Cathodic Protection (ICCP). Regression of this model to data and results yielded parameter values vary depending on the effect of the same factor.

Introduction

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. This is achieved by applying a current to the structure to be protected (such as a pipeline) from some outside source, or current can be passed between the cathode and the anode due to the difference in potential when enough current is applied, the whole structure will be at one potential; thus, anode and cathode sites will not exist. Cathodic protection is commonly used on many types of structures, such as pipelines, underground storage tanks, locks, and ship hulls [1]. The principle of cathodic protection is in connecting an external anode to the metal to be protected and the passing of an electrical direct current (DC) current so that all areas of the metal surface become cathodic and therefore do not corrode. The external anode may be a galvanic anode, where the current is a result of the potential difference between the two metals, or it may be an impressed current anode, where the current is impressed from an external DC power source. In electrochemical terms, the electrical potential between the metal and the electrolyte solution with which it is in contact is made more negative, by the supply of negative charged electrons, to a value at which the corroding (anodic) reactions are stifled and only cathodic reactions can take place. The current density and the potential of the pipe are quite high and after applying impressed current cathodic protection (ICCP) the potential decrease with decreasing the current density as shown in Fig.(1) .[2]

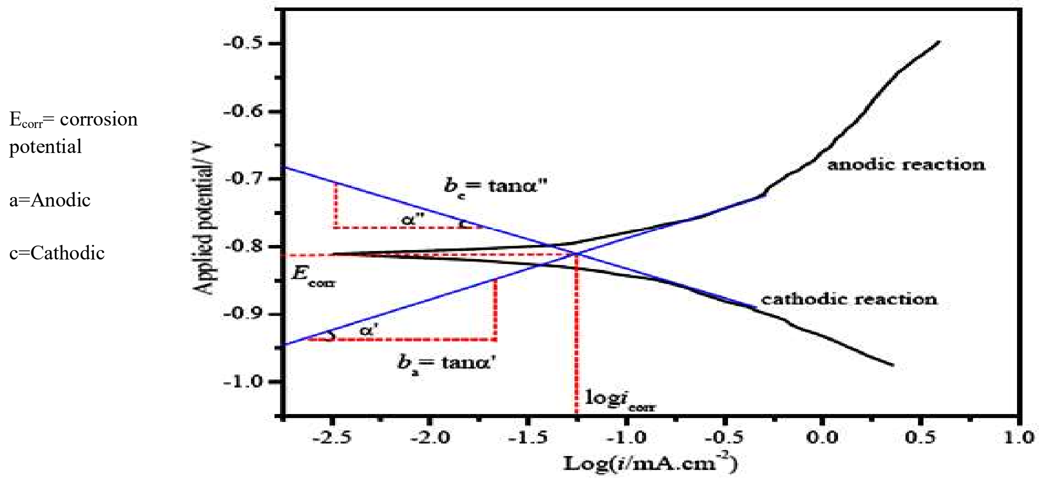

Fig.(1) The Principle of Cathodic Protection [2]

There are two main types of cathodic protection systems; there are impressed current and sacrificial anode. Both types of cathodic protection have anodes, a continuous electrolyte from the anode to the protected structure, and an external metallic connection (wire). These items are essential for all cathodic protection systems.

A sacrificial anode cathodic protection system (SACP) uses the corrosive potentials for different metals. Without cathodic protection, one area of the structure exists at more negative potential than another, which results corrosion on the structure. On the other hand, if a negative potential metal, such as Mg is placed adjacent to the structure to be protected, such as a pipeline, and a metallic connection is installed between the object and the structure, the object will become the anode and the entire structure will become the cathode. New addition object will be sacrificially corrodes to protect the structure. Thus, this protection system is called a sacrificial anode cathodic protection system because the anode corrodes sacrificially to protect the structure. Anodes materials in this system are usually made of either Mg or zinc because of these metals higher potential compared to steel structures [3].

Impressed current cathodic protection systems consist of the following essential components:

1. The current source, such as transformer/rectifiers, solar generators, etc.
2. The impressed current anodes buried in soil or immersed in water.
3. The interconnecting cables.

An Impressed Current Cathodic Protection System (ICCPS) uses a rectifier (an electrical device for converting alternating current into direct current) to provide direct current through anodes to the metal tank, piping, or other underwater components to achieve corrosion protection. The system may also be provided with a current control circuit to regulate the protection level. Such regulation is particularly useful when different structures are protected by the same current source. The most commonly used materials for impressed current anodes are graphite, high-silicon cast iron, Aluminum, Platinum coated titanium or niobium anodes and Ceramic and Mixed Metal Oxide Anodes [3].

Experimental Work

The experimental work deals with modeling of cathodic protection system for buried pipe in soil by Impressed Current Cathodic Protection System (ICCPS) technique, which has been built and assembled within a wood soil box of dimensions (150cm ×62cm ×57cm) in the laboratory. The installation of cathodic protection system was carried out to find the current required (Ammeter VICHY VC880) and potential (Voltmeter VICHY VC880) to protect a carbon steel pipe segment (100 cm) length which is buried inside the soil box in different types of environment and parameters such as soil moisture (5, 15, 60) %, pipe coating and anode distance (20, 33, 50) cm and depth (15, 35) cm. The operation of cathodic protection system involved the application of external power from DC Power Supply, (UNI-T UTP3705, 0-32V, 0-5A) to provide an applied voltage within specific standard required limits, and the resultant current for protection was measured in different specified environments.

Experimental Setup

A pipe of (2.54 cm) diameter. was trimmed electrically cutter in two identical pieces, each of (100cm) length. One bare pipe and the other was coated pipe used in cathodic protection rig of the present study. The pipe is cleaned before coating with emery paper and weld three points of copper wire at the middle and the ends of the pipe by thermite welding, and then coat it with coal tar with tapping (coating efficiency about 85%). The ends of the pipe were closed tightly using rubber stopper and thermal silicon adhesive to prevent the leakage from the environment to the pipe. Cathodic protection system builds as shown in Fig.(2).

initially bare pipe piece was buried in soil box(with different soil moisture content, (5, 15, 60)%; electric connections were fixed as shown in Fig.(2), the anode was installed and buried in many position as shown in Fig.(3), the reference electrode was placed over the soil surface directly above the buried pipe.

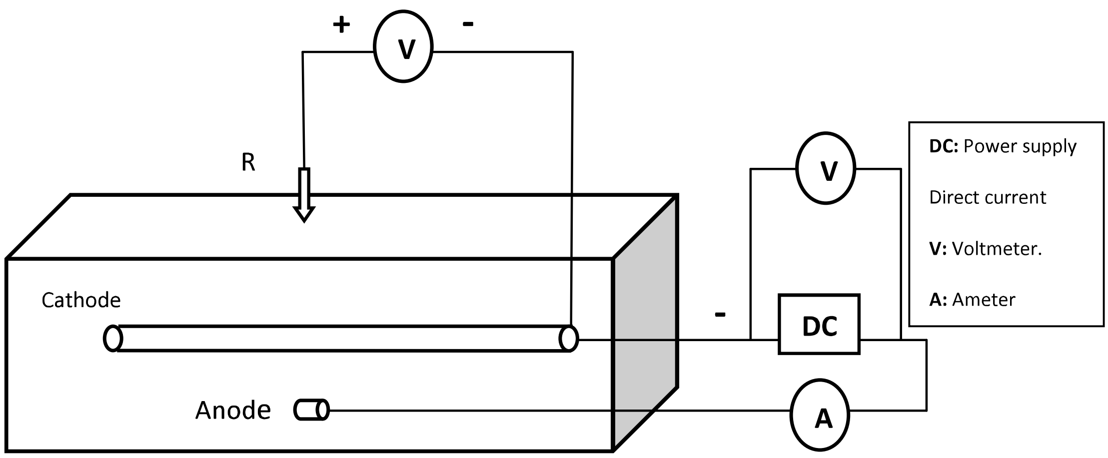

Fig.(2) ICCPS connection

Before starting operation of the system, native potential to bare pipe was read at each run using copper-copper sulfate reference electrode (CSE) on the electrolyte surface. A DC power supply was employed for voltage application, Applying voltage gradually from 0.1 volts until getting proper voltage difference for cathodic protection between the soil and the pipe to be protected. The voltage readings was set to the range of cathodic protection potential (-850 mV to -1100 mV) by varies instrument. The impressed current was recorded at intervals of 1 min over a period of 10 minutes using digital ammeter; also the corresponding supplied voltage was recorded using digital voltmeter. The off-potential was recorded after 1second of the power supply interrupted by digital voltmeter. The volts apply was supplied in the middle of the Carbone steel pipe and taking potential profile of the pipe and electrolyte (soil) along the pipe length every (10cm) that's mean (5) potential readings have been recorded with symmetric way applying all the above steps on the coated pipe at the same conditions.

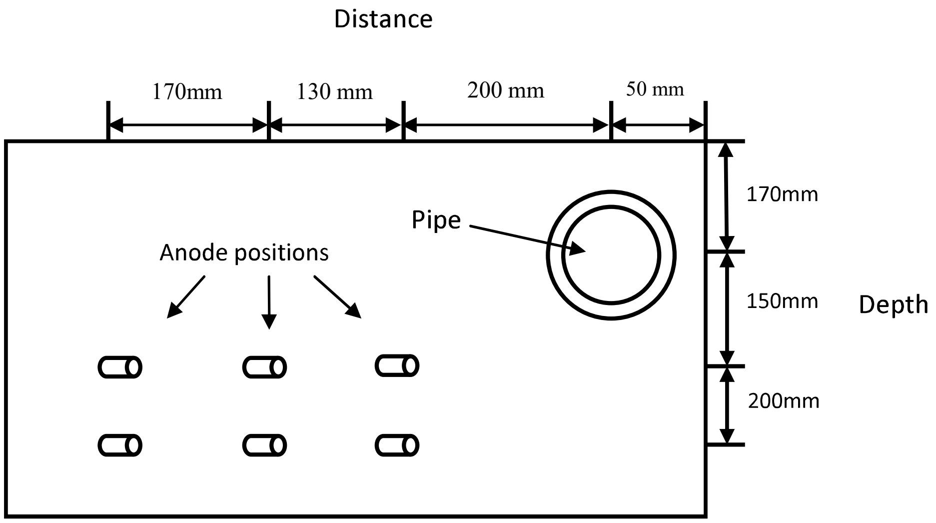

Fig.(3) Anode position and experiment runs

Results and Discussion

The effect of Anode position on:

1. Voltage required to system.

It has been noticed that the voltage required directly affected by the anode position due to increasing in soil resistivity whenever the distance increases. Also the consumption of power in moist soil is less than dry soil due to the dry soil resistivity is higher than moist soil so the current drainage in the moist soil is higher than dry soil as shown in Fig.(4).

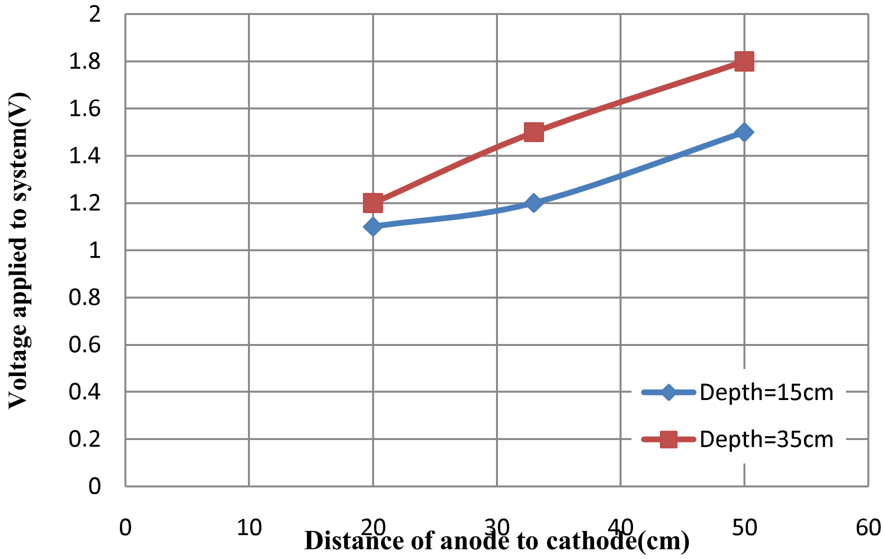

Fig. (4) The effect of anode position on the voltages applied to get cathodic protection potential (-0.85v) in bare pipe, moisture environment.

2. The Required Current Density.

The distribution of the current (that flow from anode), to the surface area of the cathode (pipe) is highly affected by the distance between cathode and anode. Increasing distance between anode and cathode awarded better distribution of the current on the surface area of the cathode and so the more protection will be achieved. Cathodic protection current density is more uniform with increasing distance between cathode (pipe) and anode. That is because increasing the distance between anode and cathode gives increases the distribution of current density on the pipe, i.e. increasing the protective surface area of the pipe (cathode). Fig.(5) shows the current density distribution along the bare pipe of moisted soil at 35cm depth.

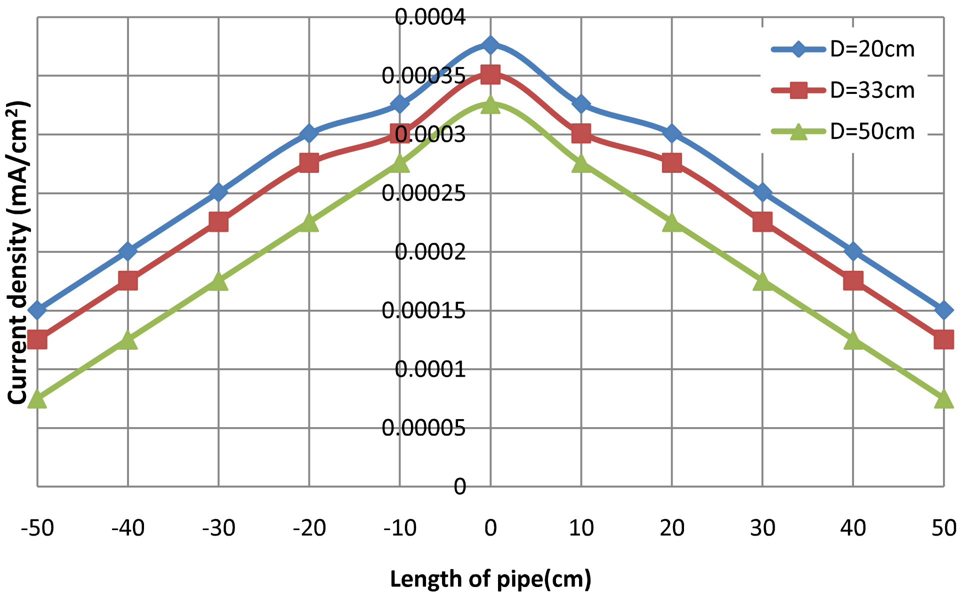

Fig. (5) Current distribution along the bare pipe of moisted soil and 35cm depth.

3. Potential between cathode and soil

The distance between anode and cathode play very important role especially on voltages applied and potential between cathode and soil via copper-*copper sulfate electrode (CSE)*, when the anode distance increase the potential decrease. In order to calculate the power required to achieve the protection, it is necessary to discuss the potential distribution along the pipe, the resistance to charge transfer across the interface increases at the point on the pipe facing the anode due to which surface kinetics controls at this point. The electrons on metal side of the interface will not be consumed readily, at the surface, due to high resistance at the interface and as a result potential is dropped at this point. While, on the other hand, all electrons near the edges, where resistance is low, are consumed immediately and, as a result, potential rises near the edges. It is noticeable also the nearest anode to the cathode has more potential than the furthest anode due to soil resistivity increase with increasing distance of anode.

Fig.(6) shows the potential distribution via (CSE) along the bare pipe in different anode position and moisted soil at a fixed 1.1 volt. Also the Figure shows the potential profile is increasing with the move away from the source of voltage applied.

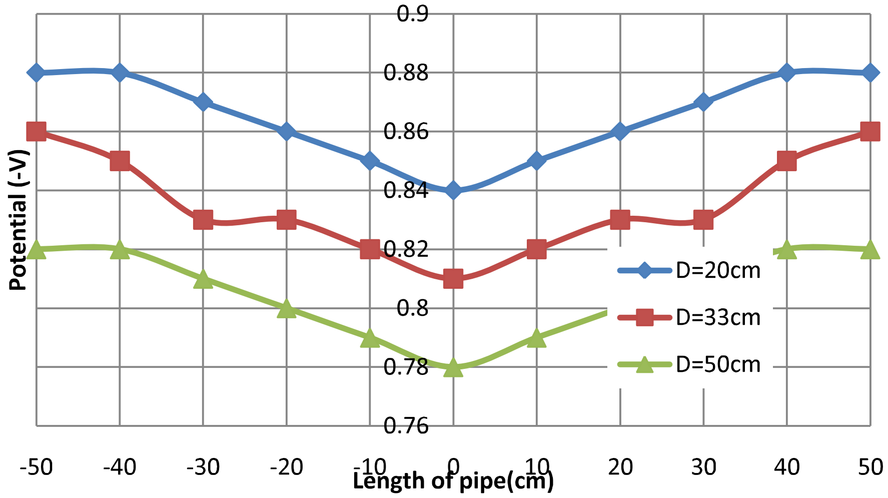

Fig.(6) the distribution of potential along the bare pipe, moisture environment and 35cm depth at fixed 1.1 volt applied.

Effect of soil moisture content and soil resistivity

The relationship of soil moisture content is directly proportional to the current density from the anode towards the cathode (structure to be protected), as the moisture content of soil increased, the cathodic protection current density increased too due to interior waters accelerate electrochemical current that passing through soil and complete the electric circuit in the cathodic protection system (CPS) from the experimental results taking three values of water content in soil (5, 15, 60) %. As is well known the relationship between soil moisture content and soil resistivity is an inverse relationship, That mean when the soil moisture content increase the resistivity of soil decrease, This leads to when the soil resistivity increase (750,1000,1500)ohm.cm the current density decrease. Fig.(7) illustrates the relationship between voltage applied and current density in different environments, Table.(1) shows Soil resistivity versus degree of corrosivity.

Table (1) Soil resistivity versus degree of corrosivity [57]

Soil resistivity, Ohm.cm	Degree of corrosivity
0 – 500	Very corrosive
500 – 1,000	Corrosive
1,000 – 2,000	Moderately corrosive
2,000 – 10,000	Mild corrosive
Above 10,000	negligible

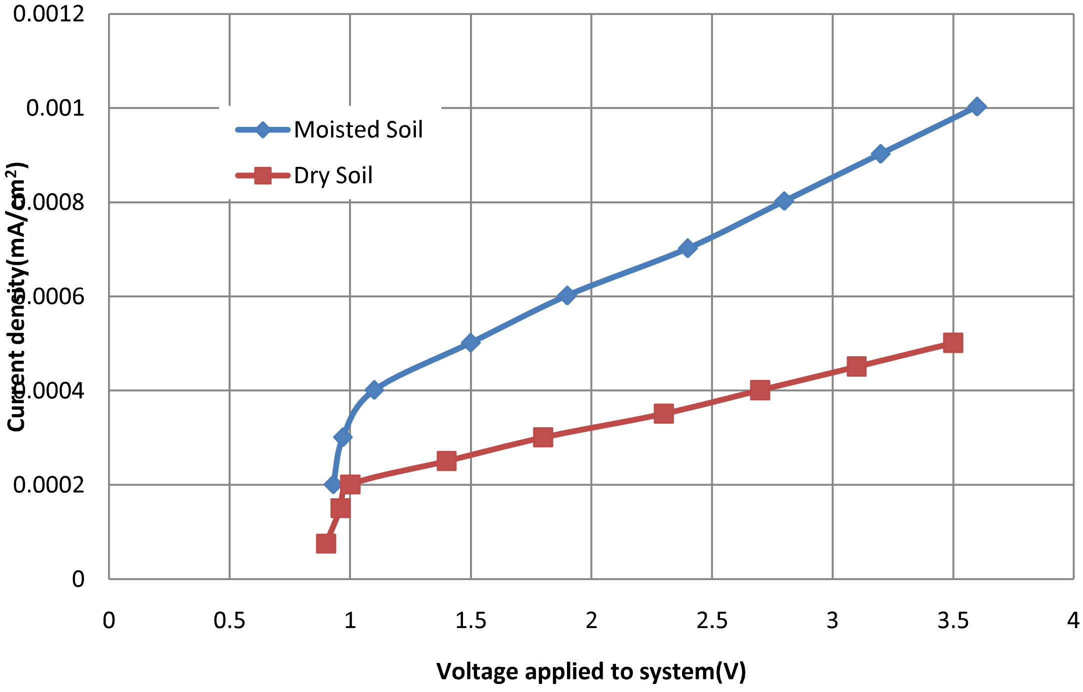

Fig.(7) bare pipe at a distance of 20cm and depth of 15cm.

Paint and Coating effect

The most effective method of mitigation corrosion on the external surface of buried pipeline is a protective coating, supplemented with cathodic protection systems. The performance of any particular coating system is directly related to the conditions encountered during the installation and operation life of the pipeline facility [4]. The bare pipe needs more applied voltages to achieve the optimum current density for protection than the coated pipe that mean needing more power to get protection. The isolation effect play very important role That's where the coated pipeline saving more power than un-coated pipeline, for example in Figure (8) at the anode distance (50cm) in moisture environment across coated and bare pipe, the bare pipe spend much power than coated pipe. The value of the current density is dependent on the quality of the coating used, the technique used for laying the pipes into the ground, types and dimensions of the pipes, environmental conditions (temperature, pH, etc.) and any measured data taken to detect and repair coating damages [5].

Additionally, the preparation and coating of pipeline joints have a significant effect on the current density demand and coating defects are frequently found in such areas. Provided the coating on the pipeline, initially has relatively few defects, the current density required will be relatively low to begin with time, the coating will undergo normal ageing and the current density requirement is expected to gradually increase.

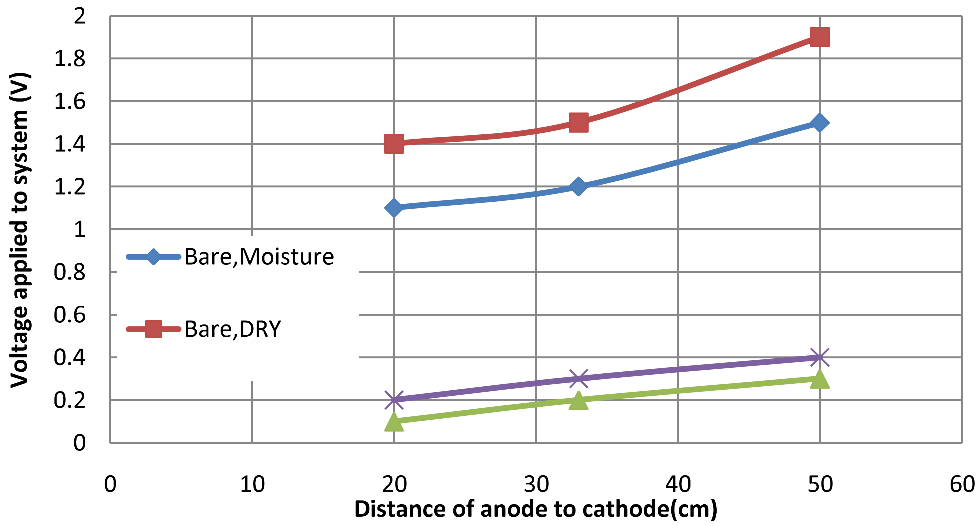

Fig.(8) the effect isolation on the voltages applied on a pipe with 15cm depth to achieve cathodic protection potential (-0.85v).

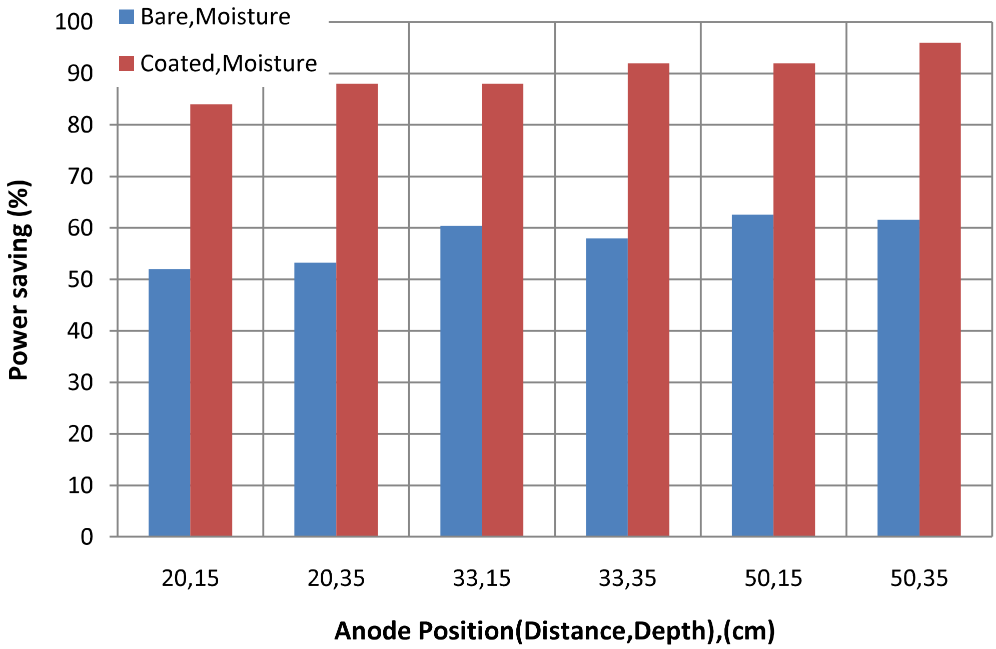

Fig.(9) power consumption of bare pipe and moist soil in different anode position.

Power consumption and saving of the system

It is necessary to calculate the power needed (consumed) to implement this system in reality. Like the way of calculating electrical power, cathodic protection power is calculated by multiplying the total current by the applied potential as per Equation (1). It is important to emphasize that the applied potential is constant, so the main effective factor is the total current [6].

$$CP_{power} = I \times V \qquad \dots (1)$$

where:

CP_{power} = Cathodic protection power in (Watts)

I = Total Current (A)

V = Applied potential in (V)

The Figures (9) and (10) below illustrate the power consumed and saved for rectifier (power supply), in different anode position and environments.

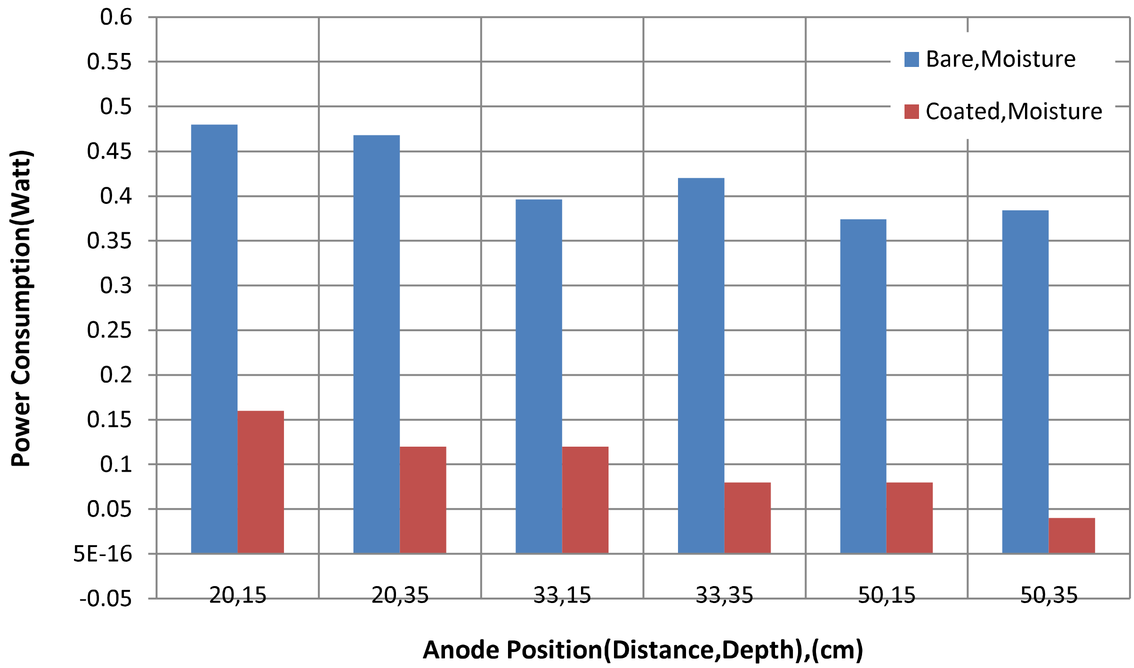

Fig.(10) power saving of bare pipe and moist soil in different anode position.

Cathodic protection model

By using Regression techniques to drive mathematical model describing the potential for cathodic protection based on 647 runs each for coated and uncoated pipe that taken to cover all parameters affecting cathodic protection as shown in equation below.

$$\xi = \beta_\circ + \beta_1 V + \beta_2 I + \beta_3 D + \beta_4 Dp + \beta_5 m \quad \ldots (2)$$

where:

ξ= Cathodic protection potential between (-0.85 to -1.1) Volt.

V= Voltage applied to achieve cathodic protection potential rang of (-0.85 to -1.1) Volt.

I= Current required to achieve cathodic protection potential rang of (-0.85 to -1.1) Volt, (mA).

D= Distance of anode to cathode, (cm).

Dp= Depth of anode from cathode, (cm).

m= Environment (soil), moisture, (%).

$\beta_\circ$, β_1, β_2,... = unknown parameters.

There are several factors affecting the cathodic protection and every factor has a special effect in terms of impact strength. By applying the above equation with the mathematical model for access to ranges of cathodic protection potentials limit.

Collecting data from experimental results bare and coated pipe applying it in Equation (2) that will be obtain:

1. Bare Carbon steel pipe.

$$\xi = 0.791+0.091\,V+0.144\,I-0.00188\,D-0.00180\,Dp-0.00537\,m \quad \ldots (2a)$$

Correlation between each factors can be get it as shown in Table (2).

Table.(2) Correlation between factors affecting cathodic protection of bare pipe.

	Potential(ξ)	*Voltage applied(V)*	*Current(I)*	*Distance(D)*	*Depth (Dp)*	*Environment(m)*
Potential(ξ)	1	0.852027938	0.6556568	-0.01731711	0.00257404	-0.032360465
Voltage applied(V)	0.852027938	1	0.5199678	0.30833687	0.209030672	-0.201146527
Current(I)	0.655656795	0.519967798	1	0.01188551	0.14330017	0.669487372
Distance(D)	-0.017317109	0.308336865	0.0118855	1	-0.06320461	-0.030707291
Depth(Dp)	0.00257404	0.209030672	0.1433002	-0.06320461	1	0.114929852
Environment(m)	-0.032360465	-0.201146527	0.6694874	-0.03070729	0.114929852	1

1. Coated Carbon steel pipe.

$$\xi = 0.467+0.742\,V-1.675\,I+0.00057\,D-0.00067\,Dp+0.2299\,m \quad \ldots (2b)$$

Correlation between each factors can be get it as shown in Table.(3).

Table.(3) Correlation between factors affecting cathodic protection of coated pipe.

	Potential(ξ)	*Voltage applied(V)*	*Current(I)*	*Distance(D)*	*Depth(Dp)*	*Environment(m)*
Potential(ξ)	1	0.901689938	0.866724971	-0.05499659	0.012378404	0.283031592
Voltage applied(V)	0.901689938	1	0.789097253	9.8232E-18	-3.01662E-18	-0.132067636
Current(I)	0.866724971	0.789097253	1	0.36229743	-0.220870514	0.332738772
Distance(D)	-0.05499659	9.82318E-18	0.362297431	1	-1.18655E-17	2.70472E-17
Depth(Dp)	0.012378404	-3.01662E-18	-0.22087051	-1.1866E-17	1	0
Environment(m)	0.283031592	-0.132067636	0.332738772	2.7047E-17	0	1

Conclusion

The following points can be concluded from the present work.

1. Conductivity (resistivity) of the soil is playing two important roles in the design criteria of cathodic protection systems. The first role is occurring when placing the anode in a high conductivity environment; more uniform current and potential distribution will take place. In case of current distribution, the higher soil conductivity the higher current passing through the soil and as a consequence the lower in power consumption. Moreover, for the potential distribution, the lower in soil conductivity, the higher in potential needed to drive the current, and as a consequence the higher in power consumption. Second role is where the hydrogen evolution may occur in thesurface of the cathode facing the anode due to the high value of the potential.

2.It is obvious that the anode at a distance of 33cm and depth of 35cm in moisted and dry soil is saving the maximum amount of power, due to the uniform distribution of current along the pipe, i.e. protection is achieved within the optimum values.

3.Coatings are the first line of defense in underground and submerged applications while coatings are the only defense in atmosphere application.

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