Cathodic Protection for Steel Pipeline Using Solar Energy

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ABSTRACT

The present work involves using Impressed Current Cathodic Protection Technique (ICCPT), to prevent corrosion of buried underground steel pipelines. Polarization method using galvanokinetic technique was used to study the behavior of steel pipelines in Iraqi soil. The soil resistivity in this work is equivalent to NaCl solution (5, 10, 15, 20 and 25) NaCl concentrations. The resistivities play a strong role in corrosion rates, where corrosion rate increases with decreasing environment resistivity and increases with increasing the concentrations of NaCl for constant surface area. The object of this study is using a cathodic protection system by impressed current supplied with solar energy panels applied to steel pipelines. The efficiency of cathodic protection depending on the soil resistivity in the present work with different electric source and solar energy source are reached to the (92.3-94.5).

Keywords: Corrosion – Cathodic Protection – Impressed Current – Buried Pipeline – Photovoltaic.

الحماية الكاثودية للانابيب الفولاذية باستخدام الطاقة الشمسية

الخلاصة

يضمن هذا البحث أستخدام تقنية الحماية الكاثودية بالتيار المسلط لمنع التأكل لخطوط الانابيب الفولاذية المغطاه او المدفونة تحت التربة. وتستخدم طريقة الأستقطاب وبأستخدام تقنية (galvanokinetic technique) تستخدم لدراسة سلوك الانابيب الفولاذية المدفونة في التربة العراقية. حيث أن مقاومية التربة في هذا البحث تكافئ بمحلول كلوريد الصوديوم NaCl بتراكيز (5, 10, 15, 20 and 25) . وتلعب مقاومية التربة دور كبير في معدل التأكل, حيث أن معدل التأكل يزداد بنقصان مقاومية التربة ويزداد بزيادة تركيز NaCl , بثبوت المساحة السطحية للنموذج. أن الهدف من هذا البحث هو أستخدام نظام الحماية الكاثودية بأستخدام التيار المسلط وتسليطة من مصدر الطاقة الشمسية غلى خطوط الانابيب الفولاذية.

كفاءة الحماية الكاثودية تعتمد على مقاومية التربة وبأختلاف مصدري الطاقة (مصدر الكهرباء التقليدية ومصدر الطاقة الشمسية) وتتراوح بين (94.5-92.3).

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INTRODUCTION

Cathodic Protection System (CPS) is used to reduce corrosion by minimizing the difference in potential between anode and cathode. Cathodic protection can be applied in practice to protect metals, such as steel, from corrosion in all soils and in almost all aqueous media [1].

There are two types of cathodic protection: Sacrificial Anode Cathodic Protection Technique (SACPT), also known as galvanic cathodic protection technique and Impressed Current Cathodic Protection Technique (ICCPT) [2, 3]. ICCPT is commonly used on many types of structures such as steel pipelines, underground storage tanks and ship hulls [4]. That utilizes an external source of DC power in order to force current flow onto a pipeline or other underground/submerged structure, hence mitigating the discharge of corrosion current from the structure to the electrolyte and reducing the loss of metal from the structure [4, 5]. (ICCP) involves application of DC electrical current to the metal surface from an external current power sources such as solar cells, thermoelectric cells, rectifiers, Turbo Generators, motor-generator sets, and wind-driven generators may be used [2]. A present work an Impressed Current Cathodic Protection (ICCP) system to reduce corrosion of steel pipelines in Iraqi soil. The impressed current is employed by using photovoltaic's cells. The corrosion rates are measured depending on Iraqi soil resistivity's values, which are (105, 55, 34, 27, and 24) Ω.cm and (4-7 PH).

EXPERIMENTAL WORK

The experimental work involves using of cathodic protection technique by Impressed Current Technique to prevent corrosion of underground steel pipelines. The impressed current was taken from electric sources and from solar energy such as shown in Figure (1). The corrosivity of soils and waters is dependent upon the soil resistivity.

Preparation of Specimens (Working Electrode)

The material that has been studied in present work was made of steel pipelines (low carbon steels grade AISI 1012). Carbon steels grade AISI 1012 are widely used in chemical, petroleum, and oil pipelines. The dimensions of the specimen were (1.5cm length and 1.5cm width).

Corrosion Rate Measurement by Weight-loss

Immersion test was conducted to determine corrosion rate using weight loss method in which a specimen with known initial weight is exposed to the corrosion environment for a specified period of time, depending upon the used solution in the test.

The corrosion rate CR, was calculated using following equation:

$$\mathrm{CR} = \frac{\Delta \mathrm{W}}{\mathrm{AT}} \quad \text{... (1)}$$

Where:

CR : Corrosion rate in gmd

ΔW : mass loss in g

A : Exposed surface area in dcm^2

T : Time of exposure in days

And also the corrosion rate can be expressed in units of milligrams per square decimeter in day (mdd), as in the equation (2):

$$gmd = 0.1\ mdd \qquad ...\ (2)$$

The conversion of corrosion rate in unit's mils penetration per years (mpy) by the following relationship:

$$C.R\ (mpy) = (1.44/D)*C.\ R\ (mdd) \qquad ...\ (3)$$

where:

mpy: mils penetration per year, 1 mils = 10^{-3} inch
D : Specific Density of metal (for steel =7.9 gm/ cm^3)
where corrosion rate can be determined by the flowing relationship [6]:

$$\text{Corrosion rate (mpy)} = 0.13\times i_{corr.}\ .\ e/D \qquad \ldots\ (4)$$

Where:

i_{corr} : Corrosion current density $\mu A/cm^2$
e : Equivalent weight (for steel =25.5)

Applying Impressed Current by Galvanokinetic Technique, Using Electrical Sources

The electrode potential was measured with respect to saturated calomel electrode, using multi-range voltmeter. According to galvanokinetic technique the current of DC power supply is held constant and the resistance of the circuit was changed. Each run was repeated twice with a third run was made when reproducibility was in doubt [8]. The values were taken from allowed current density in ICCP from the values close to corrosion current ($\mathbf{I_{corr}}$) under corrosion potential ($\mathbf{E_{corr}}$), as shown in Figure (2).

Applying Impressed Current by Galvanokinetic Technique, Using Solar Sources

Impressed current for cathodic protection could be applied by from the solar cell source.

The applied current depends on the corrosion current values, which is calculated by polarization method to get the corrosion current and impressed cathodic protection ($\mathbf{I_{corr}}$,$\mathbf{I_{cp}}$) respectively as shown in Figure(2). According to galvanokinetic technique, the current of **DC** solar cell panel, charge regulator (current controller), the current supply and constant controlled by resistance of the circuit are changed until obtaining the value of ($\mathbf{I_{cp}}$), as shown in Figure (3).

Measurements of the Efficiency of Cathodic Protection

The value of ($\mathbf{I_{cp}}$) is greatest value of current applied to cathodic protection for this specimen or sample, and then supplied this value of current to the specimen, by Potentiostat and other sources of power such as solar energy. A relationship is drowning between current and potential [7]. If the values of ($\mathbf{I_{corr}}$) after applying ($\mathbf{I_{cp}}$) are less then ($\mathbf{I_{corr}}$) before applying ($\mathbf{I_{cp}}$), it means that the specimen has been successfully protected [9]. After finding corrosion rates without CP and with CP the efficiency of cathodic protection (η_{CP}) can be determined depending on the equation:-

$$\eta_{CP} = \frac{\text{Corrosion Rate without CP} - \text{Corrosion Rate with CP}}{\text{Corrosion Rate without CP}}\ X\ 100 \qquad \ldots(5)$$

RESULTS AND DISCUSSION

Results of Corrosion Rate Determination by Weight Loss

Figure (1) shows the average corrosion rate for different environment resistivities, Electrical resistivity, is most commonly used in corrosion technology as a reciprocal of conductivity. The results indicate that the corrosion rate increases with decreasing environment resistivity and increases with increasing the concentrations of NaCl for constant surface area.

Corrosion Rate Determination by Tafel Extrapolation

The total polarization curves of a corrosion system controlled by the charge transfer (applied current) polarization are given in Table (1).

The corrosion tendency increases with increasing corrosion current density. Figure (5), shows the effect of CP on steel pipelines.

Impressed Current from Solar Energy Source

The results show that the impressed current configuration by photovoltaic panels ensure, the protection of the steel pipelines, cathodic protection criteria are obtained. The current density required for complete protection depends on the metal and on the environment. The applied current density must always exceed the current density equivalent to the measured corrosion rate in the same environment. Where applied current density $\mathbf{I_{app}}$ that taken from Table (2).

From the Figure (6) it can be shown that the corrosion rate which is determined using weight loss method, the highest corrosion rate (1.397 x10^{-2} mpy) occurs at (24 Ω.cm) soil resistivities and lowest corrosion rate (0.1822 x10^{-2} mpy) occurs at (105 Ω.cm) soil resistivity with exposure time between of (72) h. As the soil resistivity increases, the corrosion rates decreases in the following order:

(24 > 27 > 34 > 55 > 105)

These results correspond to the results of galvanokinetic polarization. The action of solar energy in present work is to supply the impressed current in DC current to be used as impressed cathodic protection current.

The values of impressed current, which are taken from solar energy, have the same values as impressed current from electrical sources (63.1, 93.9, 238.0, 206.2 and 170.0) x10^{-2} μA/cm^2.

Efficiency of Cathodic Protection Technique in this Work

When impressed current is taken from electric sources, corrosion rate is calculated by mixed potential theory, while corrosion rate of impressed current taken from solar energy is calculated by the weight loss method. The efficiency of cathodic protection depending on the soil resistivity in the present work reached to the 92.3-94.5, as shown in Table (3).

CONCLUSIONS

Soil resistivity plays a major factor in determining the corrosion rate. Generally, the lower the resistivity of the soil is higher the external corrosion rate of the steel pipelines, therefore low soi1 resistivity increases the risk of external corrosion**.**

The results show, that the impressed current configuration using the solar photovoltaic panels ensures the protection of the steel pipelines. The following observations are deduced:

a) The method is applicable to various types of grounds, depending on soil resistivity.

b) The range of the protection potentials is broad and the system can be adapted for different material constituting the pipeline.
c) Output current is controlled and can be varied.
d) The output current is high enough to protect the pipeline at low costs.

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Table (1) Corrosion rates without cathodic protection as a function of environment different soil resistivity.

resistivity **Ω.cm**	***Corrosion potential*** E_{corr} **/mV**	***Corrosion current density*** i_{corr} **μA/cm²** (10^{-1})	***Corrosion rate (mpy)*** (10^{-2})
105	-440	3.1	13.0
55	-475	4.2	17.6
34	-481	5.4	22.6
27	-518	6.9	28.9
24	-542	8.2	34.4

Table (2) The results for cathodic protection at applied current on steel pipeline specimens with tafel extrapolation method at different soil resistivities.

resistivity **Ω.cm**	*Corrosion potential* **E_{corr} /Mv**	*Corrosion current density* **I_{corr} μA/cm^2 (10^{-2})**	*Applied current density* **I_{app} μA/cm^2 (10^{-2})**	*Corrosion rate (mpy)* **(10^{-2})**
105	-431	2.1	63.1	0.88
55	-460	3.2	93.9	1.34
34	-468	4.0	238.0	1.67
27	-500	5.1	206.2	2.14
24	-512	5.8	170.0	2.43

Table (3) The efficiency of cathodic protection depending on the soil resistivity in the present work.

Soil resistivity **Ω.cm**	I.C.C.P Using Galvanokinetic polarization Efficiency **η(%)**	I.C.C.P Using Solar Energy Efficiency **η(%)**
105	93.2	94.5
55	92.3	93.1
34	92.6	92.9
27	92.5	93.5
24	92.9	93.0

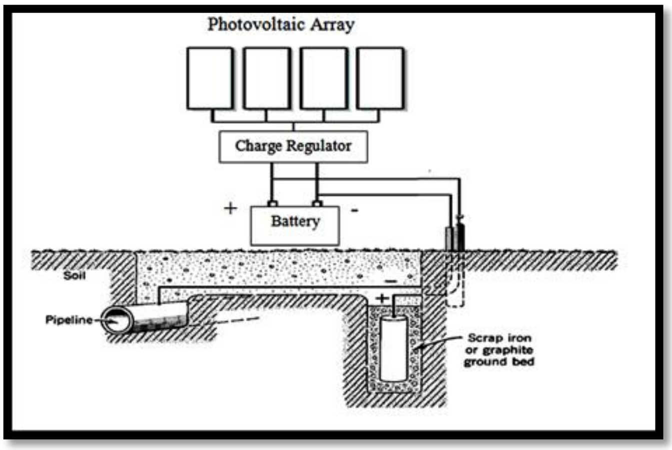

Figure (1) Supplied solar energy for cathodic protection installation [4].

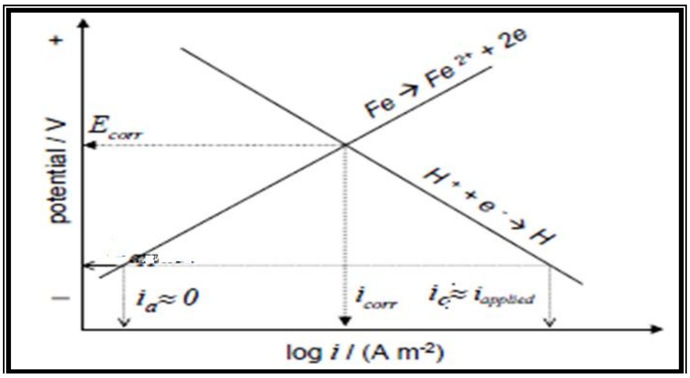

Figure (2) Polarization curve to determine values of (I_{corr},E_{corr}) [1].

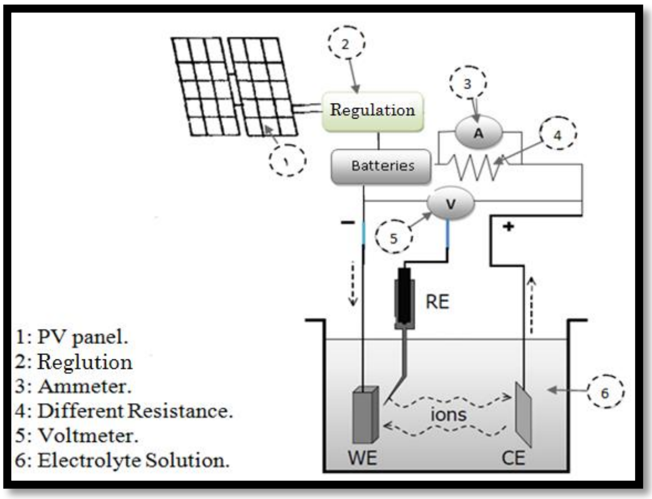

Figure (3) Sketch of cathodically protected pipe by impressed current.

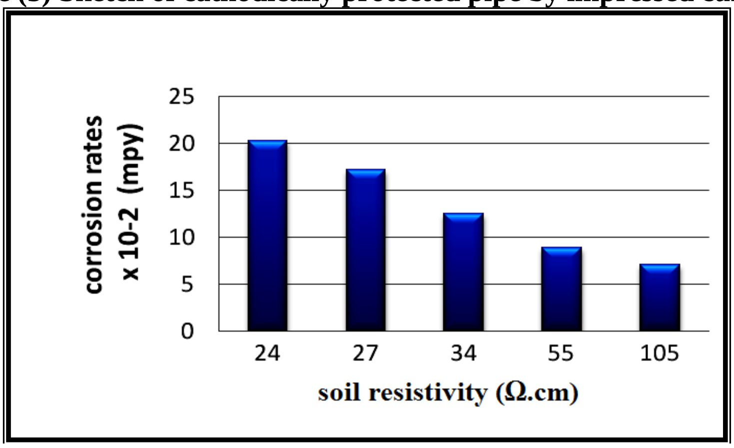

Figure (4) Average corrosion rate as a function of soil resistivity at different exposure times (24, 48, 72) h and surface area of 3 cm^2.

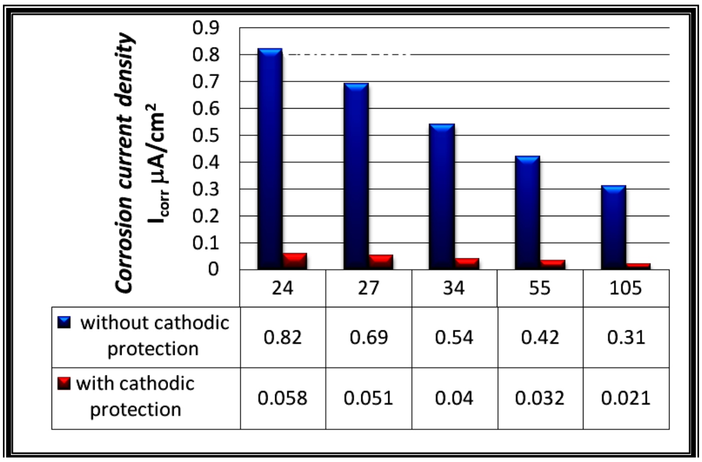

Figure (5) Effect the cathodic protection on corrosion current density of buried steel pipeline at different soil resistivity.

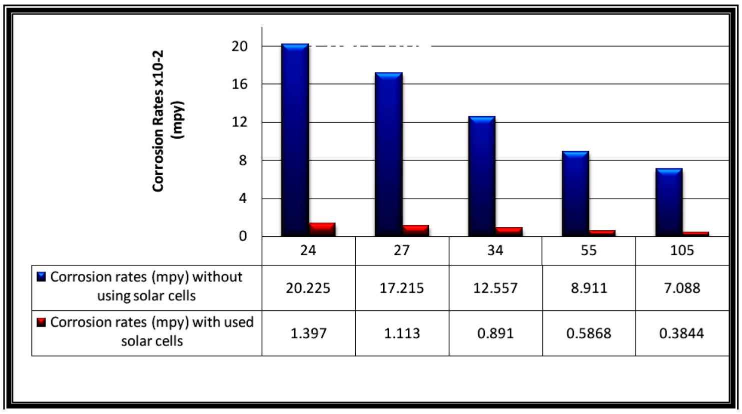

Figure (6) Effect the cathodic protection on average corrosion rates with using solar cells source for buried steel pipelines at different soil resistivity and surface area of (3cm^2).