

# **Cathodic Protection of a Steel Pipeline Structures Utilizing Concrete Coating**

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## **Summary**

This work is to development of the corrosion resistance of the steel pipeline structures utilizing concrete coating by using the cathodic protection technique to protect the structure of the coated steel pipeline structure. It deals with the matter of steel structures upon the survey periods, electrochemical dormant period because of the continuous cathodic presentation and the activation corrosion upon interruption period of this cathodic presentation and treatment this case of corrosion by using the cathodic protection technique. The initial free corrosion potential ( $E_{\text{corr}}$ ) upon intermittently intervals and corrosion rate measurement of the specimens by using full polarization curve (Tafel method) has been observed.

The results indicate that the moisture progressive within each specimen has produced different potentials along the steelpipe. Greater polarization has been associated with the submerged part of the specimen where the concrete coating resistance is at minimum. Whereas the degree of polarization is directly proportional with the level of external voltage. The results indicated that to achieve efficient design of a cathodic protection, the protected area should be divided into discrete electrochemical areas depending on the electrical resistance and steel potential to prevent the over-protection in the low electrical resistance areas. Furthermore, the results indicate that the absolute value of protection potential does not adequately to describe the electrochemical changes undergone by the polarized coated steelpipe. Owing to the flowing current between anode and cathode, the voltage drop is mainly not proportional with the electrical resistance of isolated coating, only when the coating is uniform over the entire area of steelpipe.

## Nomenclature

Symbol	Meaning	Unit
CP	Cathodic Protection.	-
AP	Anodic Protection.	-
CPS	Cathodic Protection System.	-
CPP	Cathodic Protection Principles.	-
SACP	Sacrificial Anode Cathodic Protection.	-
ICCP	Impressed Current Cathodic Protection.	-
TR	Transformer Rectifier.	-
E	Potential.	V
$E_{corr.}$	Corrosion Potential.	V
$E_{eq}$	Equilibrium Potential.	V
$E_a$	Anodic Potential.	V
$E_c$	Cathodic Potential.	V
$E_{corr\ 4}$	4-hrs Potential.	V
$E_{corr\ 24}$	24-hrs Potential.	V
$E_{prot}$	Protection Potential.	V
$E_i$	Initial Corrosion Potential.	V
$E_t$	Actual Corrosion Potential at time (t).	V
$i$	Current Density.	$\text{mA}/\text{cm}^2$
$i_a$	Anodic Current Density.	$\text{mA}/\text{cm}^2$
$i_{app}$	Applied Current.	$\text{mA}/\text{cm}^2$
$i_c$	Cathodic Current Density.	$\text{mA}/\text{cm}^2$
$i_{corr}$	Corrosion Current.	$\text{mA}/\text{cm}^2$
$i_L$	Limiting Current Density.	$\text{mA}/\text{cm}^2$
$i_o$	Exchange Current Density.	$\text{mA}/\text{cm}^2$
I	Current.	mA
$R_e$	Electrolyte Resistance.	$\Omega$
$R_p$	Polarization Resistance.	$\Omega$
CSE	Copper/Copper Sulphate Electrode.	V

## **Introduction**

Cathodic protection (CP) is an electrochemical means of corrosion control in which the oxidation reaction in a galvanic cell is concentrated at the anode and suppresses corrosion of the cathode in the same cell. Figure (1) shows a simple cathodic protection system. The steel pipeline is cathodically protected by its connection to a sacrificial magnesium anode buried in the same soil electrolyte. Cathodic protection is different from anodic protection. In cathodic protection, the object to be protected is the cathode, but in anodic protection, the object to be protected is the anode. Anodic protection (AP) can be used on only a limited number of alloys in certain restricted environments, but cathodic protection can, in principle, be applied to any metal. In practice, cathodic protection is primarily used on carbon steel. The effectiveness of cathodic protection allows carbon steel, which has little natural corrosion resistance, to be used in such corrosive environments as seawater, acid soils, salt-laden concrete, and many other corrosive environments. Virtually all modern pipelines are coated with an organic protective coating that is supplemented by cathodic protection systems sized to prevent corrosion at holidays in the protective coating. This combination of protective coating and cathodic protection is used on virtually all immersed or buried carbon steel structures [1, 2].

Cathodic protection causes changes in the chemistry of seawater near the protected structure, and this causes the precipitation of a natural coating on the structure that reduces the need for cathodic protection current. Concrete structures normally rely on the protectiveness of the concrete cover to prevent the corrosion of embedded steel. When corrosion of embedded steel occurs because of a loss of this protectiveness, cathodic protection is sometimes used to extend the life of the already deteriorated structure. For every structure there is a special cathodic protection system dependent on the structure. Basically, there are two types of applying cathodic protection systems to the metallic structures, these are [3, 4]:

- 1 - Sacrificial Anodes CP Method.
- 2 - Impressed Current CP Method.

Current distribution in cathodic protection systems is dependent on several factors, the most important of which are driving potential, anode and cathode geometry, spacing between anode and cathode and the conductivity of the aqueous environment which is favorable towards good distribution of current [5, 6].

### **Sacrificial Anode Cathodic Protection (SACP)**

The SACP is designed upon the following general pattern:

- (a) The surface area of steelwork submerged in the sea driven/buried in the bottom is calculated and the current for CP is estimated.
- (b) The total weight of sacrificial anode material required to provide this necessary current for the required design life is calculated on the basis of the ampere-hour/kilogram capacity of the chosen material (aluminum, zinc and magnesium alloys is available for SACP).
- (c) The distribution of this calculated weight of anodes is then assessed by calculation the ability of anodes of a given anode potential to "throw" current for a certain distance in given environments.
- (d) The final check, which may result obtained from (b) and (c), is to estimate the current requirement of the structure during selected periods of the design life, e.g. initially when the current for polarizing an uncoated structure will be at maximum, or during the final year of the design when the anodes will be largely consumed and have their minimum capability to produce current [7, 8].

Figure (2) shows steel pipeline bracelet zinc anodes being fitted prior to the application of the concrete based weight coat to the pipeline.

### **Impressed Current Cathodic Protection (ICCP)**

The design of ICCP for an offshore steel structures follows a similar pattern to that indicated for sacrificial anode design [7,8]:

- (a) The surface area of steelwork requiring protection is calculated and their current demands for cathodic protection are estimated.
- (b) The selection of the anode material to be employed, the number of anodes and their distribution over or in relation to the structure and the final allowance of current density are all inter-related decisions.
- (c) Having determined the anode requirements and locations then selection of the power source and related cables between it and the structure and it and the anodes is undertaken.

The power source will generally be a transformer-rectifier (TR), the function of which is to provide relatively low voltage direct current to flow from the anodes, into the seawater and onto the structure. The transformer-rectifier power source may be manually or automatically controlled. In the case of manually controlled equipment measurements of steel/sea water potentials are made at intervals and the current output from the transformer-rectifier manually adjusted by tap change

switches, or similar, in order to maintain or achieve the required steel/sea water potentials. Automatically controlled, or potentiostatic, equipment utilize continuous measurements of steel/sea water potentials from permanently installed reference electrodes and amplify these signals to achieve continuous control within pre-set levels.

### **Materials & Experimental Work**

Materials were used are the following:

1. Carbon Steel Pipe, (13 mm -diameter x 700 mm -long).
2. Brass Alloy Bar, (3 mm -diameter x 600 mm -long).

The chemical compositions are presented in table (1) & (2).

With regard to concrete coating work, the materials were used:

1. Cement. Ordinary Portland cement produced at Al-kufa cement factory.
2. Aggregate. Natural gravel of 20 mm max. size, sand is 10 mm max. size.
3. Water. Tap water is used for mixing and curing operations.

The chemical compositions are presented in table (3), (4), (5) & (6).

Moreover, the preparation of concrete coating procedure was accomplished by the mixing proportions by weight of cement, fine and coarse aggregates are 1:2:4. The ingredient proportions are kept constant throughout the experimental work. The cement content is  $350 \text{ kg/m}^3$ , w/c ratio is 0.6 for all the specimens. An electric pan mixer has been used to mix concrete ingredient. Coarse, fine aggregate and cement are first fed into the mixer and mixed in a dry state for approximately two minutes. Having obtained a homogeneous mix, greater part of the designed amount of water is added, the remaining small amount is withheld until visual assessment made as to the required amount of water to achieve the required workability.

### **Instrumentation**

1. Voltage controllable DC powers supply, providing a current of 2A max. at approximately 30V.
2. Digital multimeter type DT-830 BUZ, with DC mode.
3. Reference electrode, A copper /copper sulphate electrode (CSE).
4. Variable resistance to adjust the supply voltage to the specimens.

### **Test Procedure**

The polarization of the working electrode (steelpipe) is achieved by the application of a constant voltage sufficient to produce the level of protection. The

electrical circuit and test arrangement used is illustrated in figure (4). The variable resistances are used to adjust the supply voltage until the required potential is achieved in the specimens.

### **Results and Discussion**

Three specimens are examined (AE1, AE2, AE3). The specimens are left in the solution for nearly three months during which the corrosion potentials are monitored. Three different levels of constant current are applied to induce a cathodic shift at the submerged part of the specimens of  $-650$ ,  $-850$  and  $-1250$  mV (CSE) respectively.

Figure (5) shows the anodic and cathodic potential which have resulted from the external application of current. Figure (6) present various potential components for the tested specimens. These figures reflect the actual extent of polarization and corrosion electrode perturbation expressed in different terms. Typical potential decay curves after current interruption are shown in figure (7). It can be seen that greater proportion of decay is expected during the first 24-hrs regardless of the activation time. Figure (8) indicates that the total current flowing in the three different zones along the specimen of the same protection potential.

$$I_{\text{prot}} = I_1 + I_2 + I_3 + \dots + I_n \quad \text{----- (1)}$$

$$I_1 = \frac{E_{\text{corr}1} - E_{t1}}{R_1} = \Delta E_1 / R_1 \quad \text{----- (2)}$$

And 
$$I_n = \frac{E_{\text{corr}n} - E_{tn}}{R_n} = \Delta E_n / R_n \quad \text{----- (3)}$$

Therefore:

$$I_{\text{prot}} = \frac{E_{\text{corr}1} - E_{t1}}{R_1} + \dots + \frac{E_{\text{corr}n} - E_{tn}}{R_n} \quad \text{----- (4)}$$

These equations have an extremely significant practical implementation and enable the cathodic protection designer to estimate accurately the current distribution along various electrically connected anodic zones.

Tafel plots for the three cases are presented in the figure (9). Table (7) compares the protection current just before the termination of the prevention and protection period with the corresponding corrosion rate as determined from Tafel plots.

## **Conclusions**

The following are the most notable conclusions can be summarized as follows:

- 1- The mechanism of the polarization behavior of steelpipe structure in aqueous solution is a fundamental different because of the high resistance of concrete coating and the alkali environment in which becomes the dominance factor on the polarization trends and eliminate or confined the effect of polarization type technique of the electrode. Also, the results indicated that the relationship between the steelpipe potential and flowing current in calculation the electrical resistance of concrete coating is extremely important in account of the effect of environment in progressive or repulsion the corrosion processes.
- 2- The absolute value of the protection potential does not adequately describe the probable electrochemical changes undergone by the polarized steelpipe, unless taken in conjunction with other polarization related current and potential parameters. 4-hrs or 24-hrs decay criteria provide different information when used for system of different corrosion activity. It is, thus, not a reliable basis for performance evaluation.
- 3- The instant off potential ( $E_{IOP}$ ) provides the thermodynamic tendency for corrosion without providing quantitative information. It may lead to wrong conclusion and needs to be seen in conjunction with other electrochemical parameters.
- 4- An important setback of ( $E_{IOP}$ ) criteria arises when ( $E_{IOP}$ ) approaches ( $E_{prot}$ ). In theory, this case represents the event when the actual polarization, as opposed to the nominal polarization, becomes zero with very small or no current flowing in the outer circuit.
- 5- High potential shift produces high protection current. However, regardless of the type of protection techniques, the results indicate that the measured cathodic current is continuously decreasing with the activation time.
- 6- The main shortcoming of the recent protection performance criteria is that they have not comprised neither based on an examination of the actual metal surface after any given period or level of protection. In fact, in certain circumstances, these criteria may provide false indications.

## **References**

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- [5] **LaQue. F. L.**, “Theoretical Studies and Laboratory Techniques In Sea Water Corrosion Testing Evaluation”, Corrosion, pp.303, April, 1956.
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**Table (1) Chemical composition of the steelpipe used.**

Materials	Composition %										
	C	Si	P	S	Cr	Mo	Ni	Cu	Mn	V	Fe
Carbon Steel	.649	.255	.012	.022	.102	.006	.042	.032	.935	.002	Rem.

**Table (2) Chemical composition of the brass bar alloy used.**

Materials	Composition %									
	Zn	Fe	Si	Mn	As	Al	Ni	Sb	S	Cu
Brass Alloy	30	.007	.004	.0088	.005	.012	.0004	.0084	.0025	Rem.

**Table (3) Percentage oxide composition & main compounds of cement.**

Oxide	Content %
SiO <sub>2</sub> , Silica	21.6
CaO, Lime	61.2
MgO, Magnesium Oxide	3.6
Fe <sub>2</sub> O <sub>3</sub> , Ferric Oxide	3.24
Al <sub>2</sub> O <sub>3</sub> , Aluminum Oxide	5.36
SO <sub>3</sub> , Sulfur Trioxide	2.5
Loss on Ignition	1.5
Insoluble Residue	0.5
Main compounds	% by wt. of cement
C <sub>3</sub> S, Tricalcium Silicate	37.88
C <sub>2</sub> S, Dicalcium Silicate	33.35
C <sub>3</sub> A, Tricalcium Aluminate	8.2
C <sub>4</sub> AF, Tetra Aluminoferrite	9.85

**Table (4) Sieve analysis of coarse aggregate.**

Sieve size (mm)	Cumulative percentage passing	Limit of Iraqi Specification No. 45/1984
37.5	100	100
20	92.8	95-100
10	26.3	30-60
4.75	2	0-10

**Table (5) Sieve analysis of fine aggregate.**

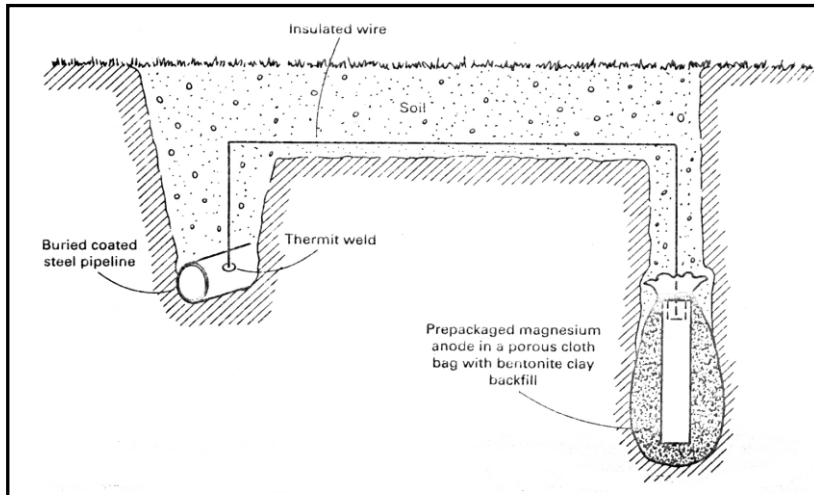
Sieve size (mm)	Cumulative percentage passing	Limit of Iraqi Specification No. 45/1984
10	99.3	100
4.57	91.9	90-100
2.36	78.96	75-100
1.18	69.6	55-90
0.6	55.9	35-59
0.3	30.6	8-30
0.15	8.9	0-10

**Table (6) Chemical analysis of tap water.**

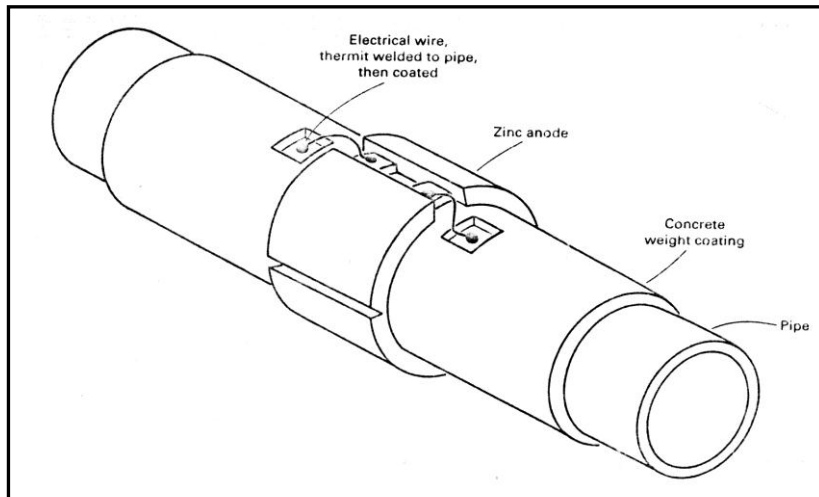
Ions	Concentration (PPM)
Cl <sup>-</sup>	156
SO <sub>4</sub> <sup>2-</sup>	49
Ca <sup>++</sup>	68
Mg <sup>++</sup>	28
pH value	7.60

**Table (7) Protection current and corrosion current.**

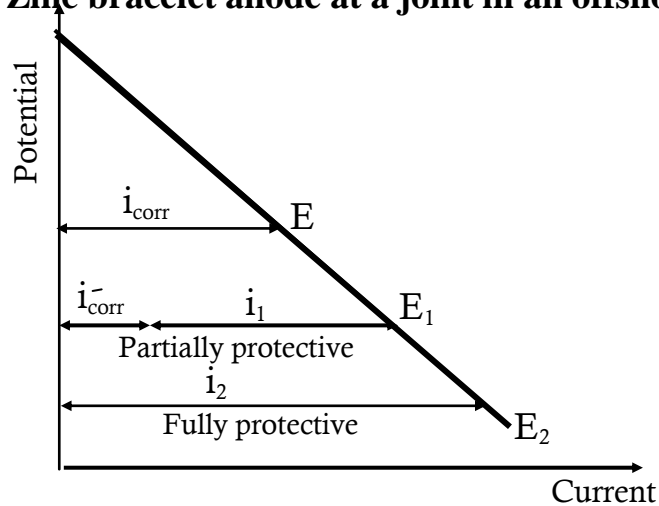
Testing	I <sub>corr</sub> (mA)	I <sub>prot</sub> (mA)
Prevention	0.066	0.142
Corrosion	0.25	-
Protection	0.11	0.66



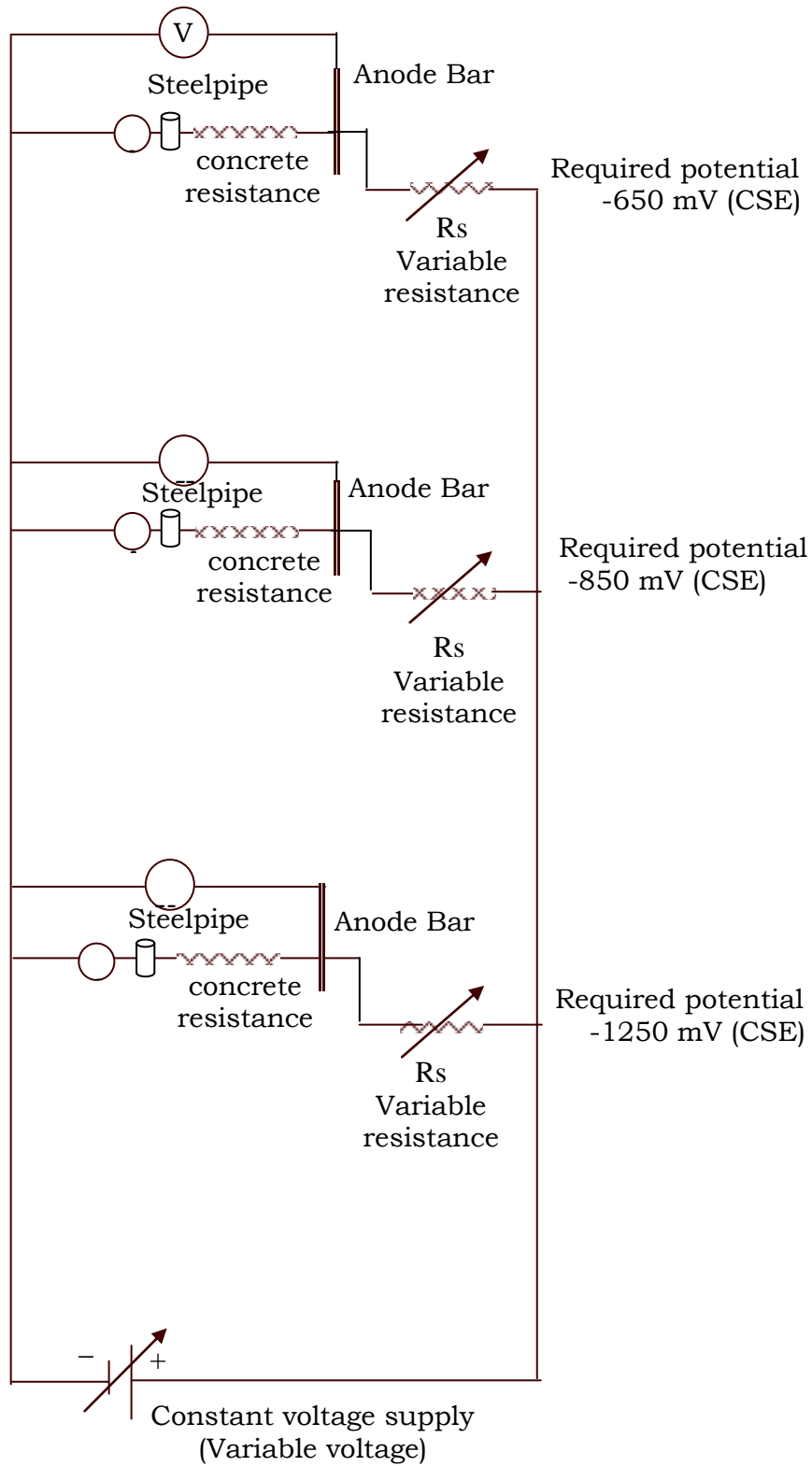
**Figure (1) CP of a buried steel pipeline using a buried magnesium anode.**



**Figure (2) Zinc bracelet anode at a joint in an offshore steel pipeline.**



**Figure (3) Principle of CP illustrated on a potential-current diagram.**



**2A maximum/ 30 V**

**Figure (4) Electrical schematic circuit for applying constant voltage controlled specimens.**

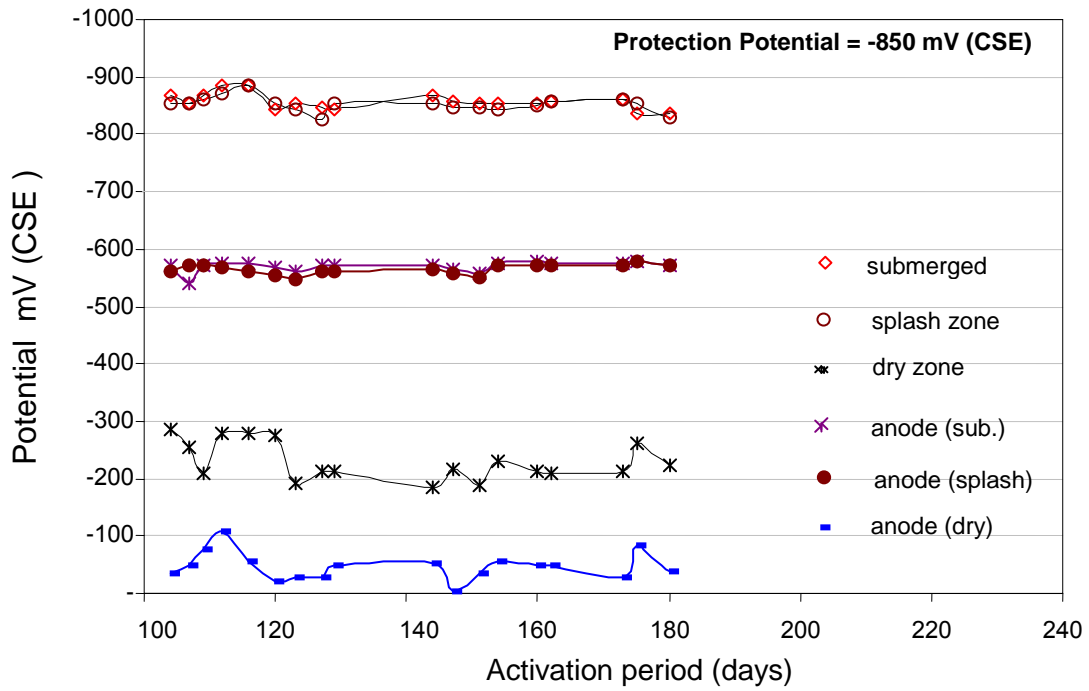


Figure (5) Change in potential with activation period for the cathode and the anode of the specimen (AE2).

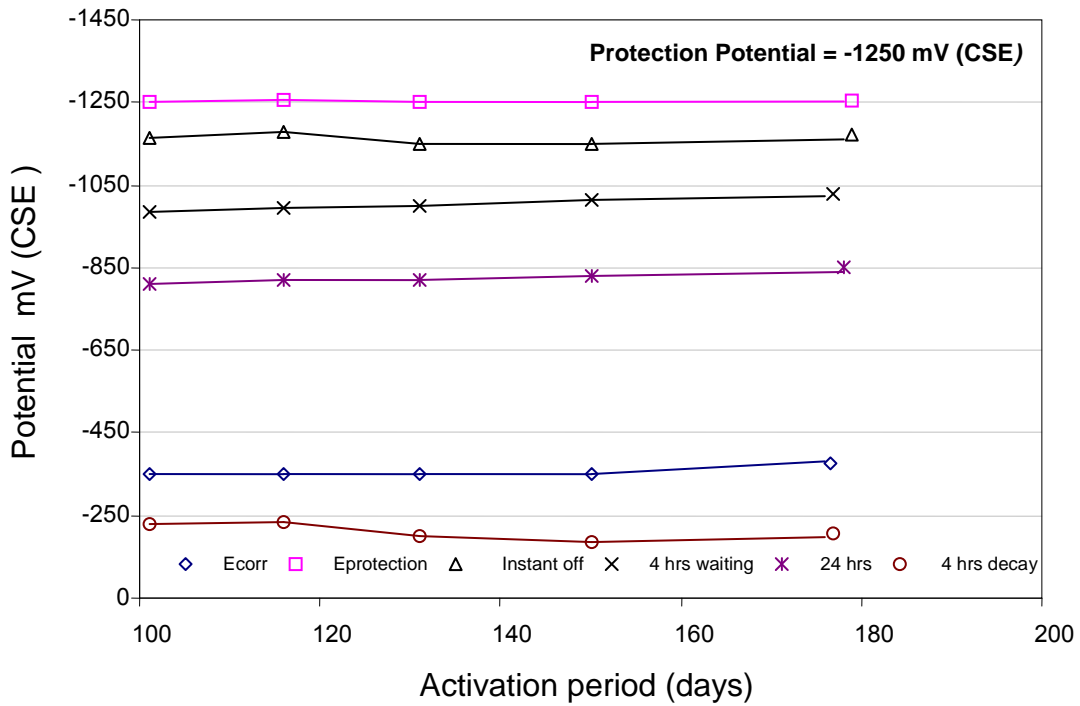


Figure (6) Change in potential parameters for the specimen (AE3).

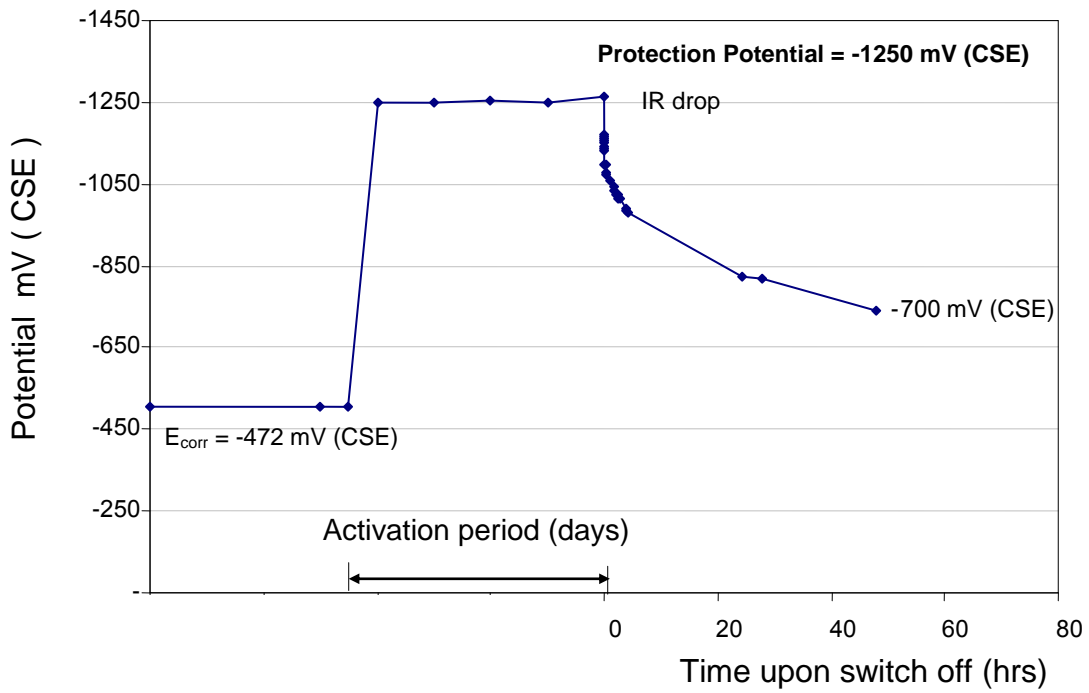


Figure (7) Potential decay curve upon current switches off for specimen (AE3).

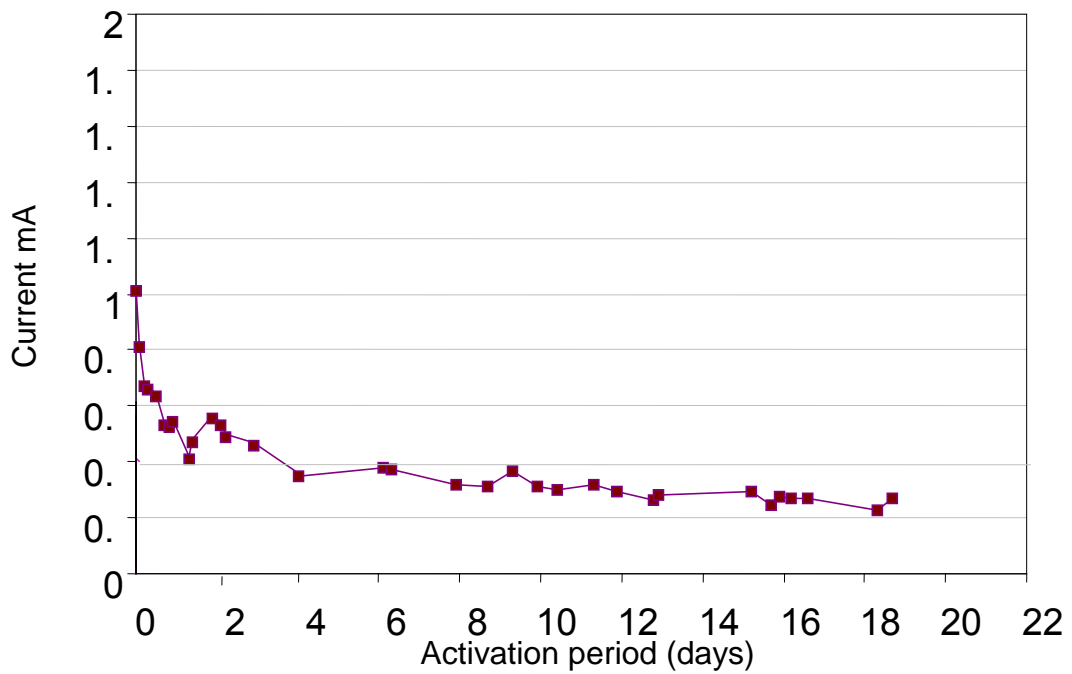


Figure (8) The flowing current of the specimen AE2 during activation period.

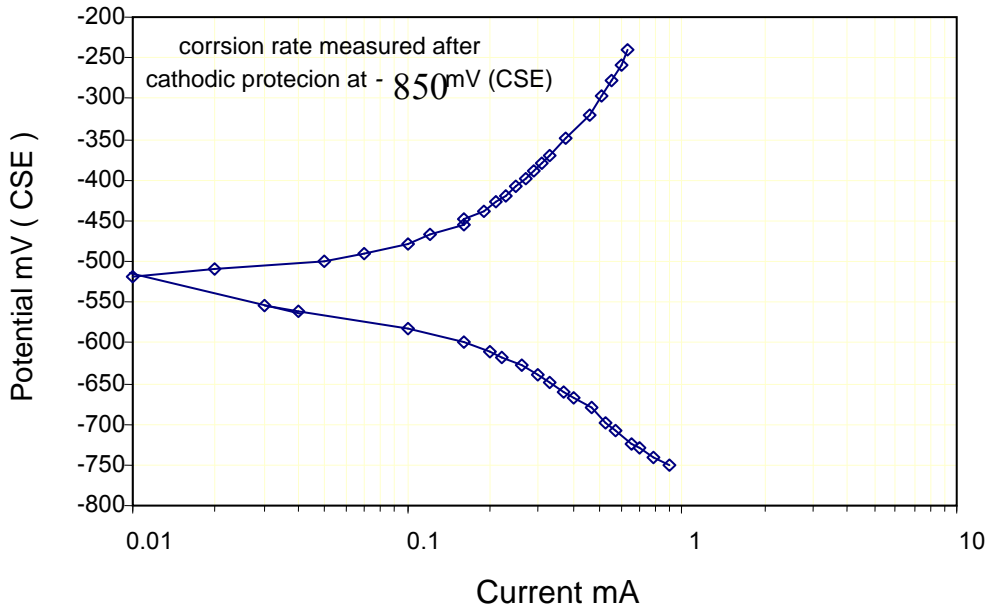
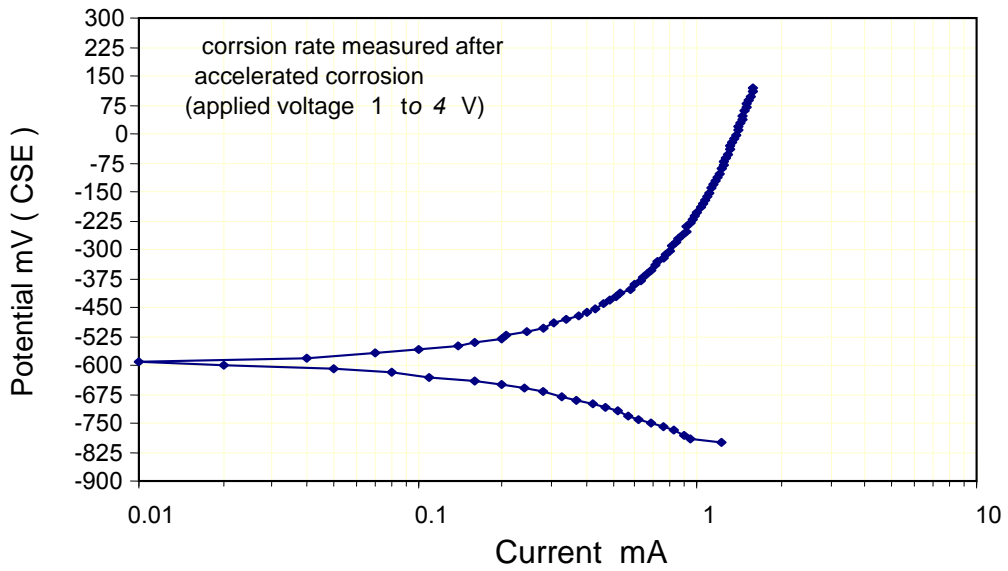
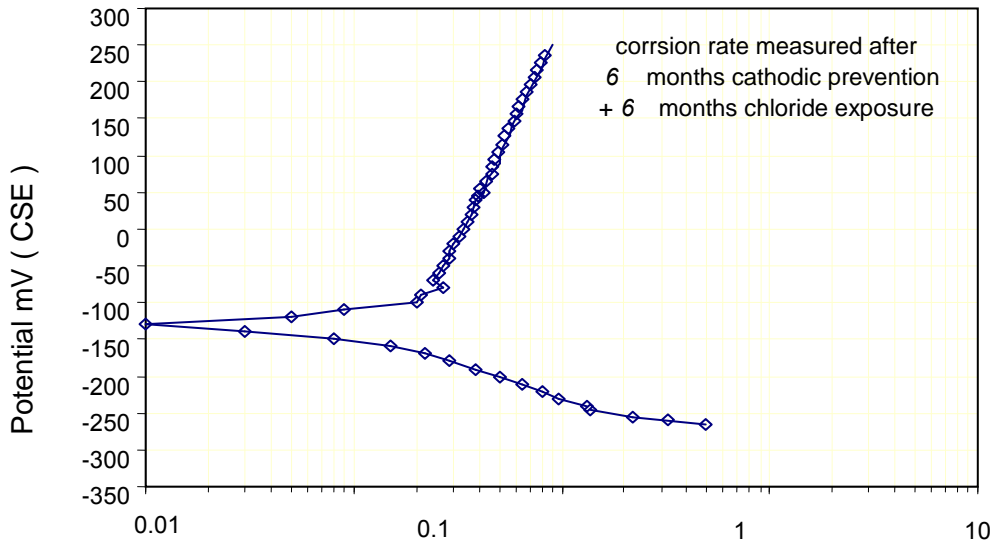


Figure (9) Tafel plots for the specimen AD1 after cathodic prevention, corrosion and cathodic protection.