Corrosion Control of a Steel Pipeline in Aqueous Chloride Solutions by Using CP Technique

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Abstract

The aim of this work is to improve the corrosion resistance of the steel pipeline structures utilizing concrete coating by using the cathodic protection technique. It deals with the matter of steel structures upon the survey periods, electrochemical dormant period because of the continuous cathodic preventation and the activation corrosion upon interruption period of this cathodic preventation and treatment this case of corrosion by using the cathodic protection technique. The initial free corrosion potential (E_{corr}) upon intermittently intervals and corrosion rate measurement of the specimens by using full polarization curve (Tafel method) has been observed. The required level of protection potential is achieved by using potentiostatic controlled potential.

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 clearly indicated that to achieve efficient design of a cathodic protection, the protected area should be divided into discrete electrochemical areas, these areas are depending on the electrical resistance and steel potential which prevent the over-protection in the low electrical resistance areas when applying the designing criteria on the high 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. The instant off potential value (E_{IOP}) does not provide quantitative informations about the state of corrosion. 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. Also, the results indicated that the relationship between the steelpipe potential and flowing current in calculated the electrical resistance of concrete coating is extremely important in account of the effect of environment in progressive or repulsion the corrosion processes.

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السيطرة على تآكل الأنابيب الفولاذية في محاليل كلوريدية باستخدام تقنية الحماية الكاثودية

الخلاصة

يهدف البحث إلى تطوير مقاومة التآكل لحديد هياكل الأنابيب الفولاذية المطلية بطلاء كونكريتي باستخدام تقنية الحماية الكاثودية . لقد تمت دراسة ما يمكن ان تتعرض لـه هياكـل الأنابيـب الفولاذية خلال الخدمة من خمول كهروكيمياوي بسبب الوقاية الكاثوديـة المـستمرة وكيفيـة حصول التآكل الفعال خلال فترة توقف هذه الوقاية وكيفية معالجة حالة التآكل هـذه بواسـطة الحماية الكاثودية وذلك من خلال مراقبة جهد التآكل الحر (.Ecorr) وعلى فترات زمنية متقاربة وقياس معدل التآكل للنماذج بطريقة منحني الاستقطاب الكلي (Tafel method) .

أشارت النتائج إلى أن التدرج الرطوبي للنماذج أدى إلى حدوث خلية نصف خلية مختلف عثـى طول هيكل حديد الانبوب نتج عنه استقطاب كاثودي عالي فـي المنـاطق المغمـورة بمحلـول الفحص عندما تكون التغطية الكونكريتية اقل ما يمكن مقارنة مع الاستقطاب فـي المنـاطق الجافة، ويتناسب طرديا" هذا الاستقطاب مع الجهد الخارجي المسلط . كما أشارت النتائج إلـى أن تحقيق حماية كاثودية مرضية يتطلب تقسيم المنطقة المراد حمايتهـا كاثوديـا" تبعـا" إلـى المقاومة الكهربائية وجهد نصف الخلية للحديد لمنع حصول فرط الحمايـة فـي المنـاطق ذات المقاومة الكهربائية القليلة عند تطبيق المعايير التصميمية علـى المنـاطق ذات المقاومـة الكهربائية العالية. كذلك تبين أن طبيعة التغيرات الكهروكيمياوية التي تحدث نتيجة اسـتقطاب الأنبوب الفولاذي لا يمكن تفسيرها بشكل كافٍ من قيمة أو كمية جهد الحماية ، كما أن قيمـة فرق الجهد اللحظي (E IOP) بعد الإيقاف لا تعطي معلومات كافية عن حالة التآكل .

كما أظهرت النتائج أن ظاهرة الاستقطاب لهيكل الأنبوب الفولاذي ذات آلية تختلف جوهريا" عنها في المحاليل السائلة بسبب المقاومة العالية للطلاء الكونكريتي والمحيط القاعدي بحيث أصبح العامل المهيمن على سلوك الاستقطاب. كذلك أشارت النتائج إلى أن العلاقة بين جهد الأنبوب الفولاذي المطلي مع التيار المار في احتساب مقاومة الطلاء الكونكريتي هي مهمة جداً في تحديد تأثير المحيط في تسهيل أو عرقلة عملية التآكل .

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Nomenclatures

Symbol	Meaning	Unit
CP	Cathodic Protection.	-
CPS	Cathodic Protection System.	-
CPP	Cathodic Protection Principle.	-
SACP	Sacrificial Anode Cathodic Protection.	-
ICCP	Impressed Current Cathodic Protection.	-
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_{IOP}	Instant Off Potential.	V
E_i	Initial Corrosion Potential.	V
E_t	Actual Corrosion Potential at time (t).	V
ΔE	Potential Shift.	V
i	Current Density.	mA/cm^2
i_a	Anodic Current Density.	mA/cm^2
i_{app}	Applied Current Density.	mA/cm^2
i_c	Cathodic Current Density.	mA/cm^2
i_{corr}	Corrosion Current Density.	mA/cm^2
i_{prot}	Protection Current.	mA/cm^2
I	Current.	mA
$V_{app.}$	External Applied Voltage.	V
R	Coating Resistance.	Ω
R_e	Electrolyte Resistance.	Ω
R_p	Polarization Resistance.	Ω
CSE	Copper/Copper Sulphate Electrode.	V
AK	Test Specimens.	-
AD1	Test Specimens No.1.	-
AD2	Test Specimens No.2.	-
AD3	Test Specimens No.3.	-

1. Introduction

Corrosion may be defined as the electrochemical reaction of a metal in the surrounding environment in which the metal itself is a reactant and is oxidized (loss of electron) to a higher valency state, whilst the other reactant, an electron acceptor, in the solution is reduced to a lower valency state. This reaction results in the formation of compounds that are referred to as corrosion products and if allowed them to produce will result in the deterioration of the metallic construction or component of the metallic structures. Usually most metals are basically unstable and have a tendency in most environments to

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revert back to their more stable state [1]. The principal methods for preventing corrosion of the steel pipeline structures are:

1- Coatings.
2- Insulated Joints.
3- Cathodic Protection.

Coatings normally are intended to form a continuous film of an electrically insulating material over the metallic surface to be protected. The function of such a coating is to isolate the metal from direct contact with the surrounding electrolyte and to interpose such a high electrical resistance in the anode-cathode circuit, so that there will be no significant corrosion current flowing from the anode to the cathode.

Insulated joints are used to break the metallic electrical connection between anode and cathode by preventing the flow of current between the two electrodes. Insulated joints can be used at the junction of two dissimilar metals but obviously would not be effective in the control of localized corrosion cell on the surface of the structure [2].

Cathodic protection (CP) could be defined as the use of direct electrical current from an external source to oppose the discharge of corrosion current from anodic areas [3].

NACE Standard RP 01-69, Recommended Practice for Corrosion Control on Underground or Submerged Metallic Piping Systeme, defines cathodic protection as a technique for preventing the corrosion of a metallic surface. This is done by making that surface a cathode in an electrochemical cell. It is obvious if the entire area of the exposed metal surface could be made to collect current, it would not corrode because the entire surface would be cathodic.

This is what cathodic protection does. Direct current is forced to flow from a source external to the metallic structure onto all surfaces of the metallic structure. When the current is properly adjusted, it will overcome the corrosion current flowing from the structure and there will be a not current flow onto the structure surface at all points [4]. For every structure, there is a special cathodic protection system dependent on the type of the structure. Basically, there are two types of applying cathodic protection systems to the metallic structures, these are:

1 - Galvanic or Sacrificial Anodes. (Sacrificial Anode CP Method).

2-Rectifier Groundbeds (Impressed Current CP Method). Current distribution in cathodic protection systems is dependent on several factors, the most important factors 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. The corrosion engineer has wide control over the geometry of the anode and the driving potential of the system, but he is seriously limited with respect to the spacing between the anode and the cathode [5,6].

2. Cathodic Protection Principle (CPP)

Lowering the potential below the equilibrium potential (E_{eq}) given by Nernst equation, the metal condition moves into a zone of immunity, the region where electrochemical attack, cannot occur.From figure (1), [7,8] under freely corroding conditions, the specimen has a mixed corrosion potential (E) and is corroding at a rate

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equivalent to (i_{corr}). In cathodic protection an external current (i_1) is supplied to the corroding metal by an auxiliary anode, so that the potential of the specimen is lowered to (E_1). Then the specimen will be partly protected, since the corrosion rate will have been reduced from (i_{corr}) to (i'_{corr}). if the externally applied current is increased to (i_2), so that the potential is lowered to (E_2), the reversible potential of the anodic reaction, anodic dissolution will be stopped. As a result, there is no net loss of metal.

Essentially, the whole surface of the object is then providing sites only for cathodic reaction, which will be oxygen reduction, hydrogen ion reduction or both. The balancing anodic reaction occurs in a connected anode. This is the basis of cathodic protection of metals.

3. 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 are available for SACP).

(c) The distribution of this calculated weight of anodes is then assessed, by calculating 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 polarising 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 [9,10].

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

4. 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 [9,10]:

(a) The surface area of steelwork requiring protection is calculated and its current demand for cathodic protection is 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 are undertaken.

The power source will generally be a transformer-rectifier (TR), the function of which is to provide relatively low voltage is 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

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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.

5. Experimental Work
5.1 Materials

Details of the materials used are as follow:

1. Carbon Steel Pipe, (13 mm - diameter x 650 mm -long).
2. Brass Alloy Bar, (3 mm -diameter x 550 mm -long).

The chemical compositions are presented in table (1) & (2). The analysis is done in the central device for standardization and the quality control.

For the concrete coating work, the materials used are as follow:

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). The analysis is done in the national center for construction laboratories and research.

5.2 Preparation of Concrete Coating

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 kg/m^3, water / cement ratio (w/c) 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.

5.3 Test Specimens

The test specimens are steelpipes with concrete coating of dimension (9 x 10 x 60) cm. The brass bar anode is secured in the surface of the specimen parallel to the steelpipe, the distance between the brass bar (anode) and the steelpipe (cathode) is 35-mm. Figure (3) shows that the test specimen details used. The specimens are partially exposed to 3.5 % the sodium chloride aqueous solution.

5.4 Instrumentation

1. Potentiostate system type AMEL model 551.
2. Digital multimeter type DT-830 BUZ, with DC mode.
3. Reference electrode, Acopper /copper sulphate electrode (CSE).

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5.5 Test procedure

Arrange the connection of the electrical circuit for protection using potentiostatic system is as shown in figure (4). The steelpipe (cathode) is connected to the working electrode (W.E) terminal of the potentiostate whereas the brass bar (anode) is connected to the auxiliary electrode (A.E) terminal of the potentiostate. The porous end of the reference electrode is dipped in the aqueous solution and connected to the reference electrode (R.E) terminal of the potentiostate. The setup is turned on, with the potential and current measuring device on DC mode. Free corrosion potential (E_{corr}), (open circuit electrode potential), the potential of the working electrode measured with respect to a reference electrode when no current flow in or out it (the current meter read zero), is recorded for the steelpipe (cathode) and brass bar (anode) along the length of the specimen. Regulating the internal voltage of the potentiostate to be identical to that of the measured (E_{corr}). Then, turn the cell on and increases the internal voltage of the potentiostate gradually to polarize the steelpipe to the required protection potential, −850 mV (CSE) in the submerged part of the specimens.

6. Results and Discussion

The protection level of − 850 mV (CSE) is examined for the specimens. The variation of the protective potential upon energization of the system and during the activation period is shown in figure (5). This figure indicates that a good control has been achieved for submerged and splash zones of the specimen. The dry zone shows distinctly lower potential shift. Figure (6) shows the nominal potential shift at the submerged and dry zones. The nominal potential shift is defined as, the difference between the initial corrosion potential and the newly attained potential during cathodic polarization . This figure clearly demonstrates the influence of coating resistance on the degree of polarization induced for any given value of externally applied voltage. The behivour of the flowing current has been monitored and presented in figure (7), it is showed that the current exhibits continuous decreases during activation time but tend to stabilize after about three months of operation. The feeding voltage, figure (8), shows fairly constant value all over the activation period. The feeding voltage is expressed as the voltage difference between the anode and the cathode. Figure (9) shows the potential variation of the anode and cathode. Figure (10) presents the potential parameters which are monitored during the activation period. This figure clearly shows that greater waiting time upon circuit cut off has produced greater potential recovery. Figure (11) shows the potential decay of specimen which indicates that there is a potential polarization of −132 mV (CSE) after 48-hrs from current interruption. The polarization of the electrode potential with time is further illustrated in figure (12), which monitors the actual potential shift as compared with the nominal potential shift.

Figure (13) shows that the potential distribution curve along the specimen upon a potential shift of the most anodic part of the steelpipe from $E_{corr} = − 445$ to $E_{polarzation} = −1140$ mV. It can be noted that the potential shift is proportional with the feeding voltage regardless of the position with

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respect to water level. The curve indicates that the submerged and splash zones acquire nearly constant potential and that the potential shift beyond the splash zone has been reduced. The total potential shift of the submerged part of the specimens ADI is about - 695 mV compared with - 400 mV at the dry part of the same specimens.

Figure (14) presents the parallel polarization of the anodic brass bar electrode, it is interesting to note that the cathodic polarization at the dry zone is equal to the anodic polarization at the submerged zone, and the cathodic polarization at the submerged zone equals the anodic polarization at the dry zone. It is found that the externally applied voltage (V_{app}) is equal to the cathodic polarization of the steelpipe minus the anodic polarization of the brass bar anode both at the dry zone. Also (V_{app}) equals the cathodic polarization of the steelpipe minus the anodic polarization of the anode bar both at the submerged zone. Thus:

$$V_{app} = Cathodic\ \Delta E_{dry} - Anodic\ \Delta E_{dry}\ (1)$$
and
$$V_{app} = Cathodic\ \Delta E_{sub} - Anodic\ \Delta E_{sub}\ (2)$$

The instant off potential is theoretically the polarized potential of the steel-electrolyte interface independent of the position of the reference electrode relative to the coated steel pipeline. The difference between the protection potential (E_{prot}) and the instant off potential (E_{IOP}) presents the IR-drop across the electrolyte due to electrolytic resistance. Consequently, the IR-drop is dependent on the amount of the flowing current (I) and the coating resistance (R). The coating resistance

cannot, always, be determined from IR-drop value and the corresponding measured external current. Only when the resistance of the coating is uniform over the entire area that the IR-drop is directly proportioned with the resistance through Ohm law:

$$Voltage\ Drop = I_{measured} \times R\ \ \ (3)$$

The potential decay upon the interruption of the protective current and subsequent immediate disappearance of the ohmic component of the circuit the potential moves at substantially slower rate towards the original corrosion potential before cathodic polarization. The results clearly show that most of the decay may occur during the first 24-hrs after interruption. Figure (15) shows that the rate of decay is actually dependent on the amount of potential shift. The lower of the potential shift is the attendance of a stable potential.

Figure (16) indicates that the total current flowing in the three different zones along the specimen of the same protection potential. This observation is of practical significance in that current measurements can not be relied upon to assess the degree of protection or the amount of current received by different parts of the structure unless reasonably accurate distinction between different anodic areas is established. For this reason, it is not possible to determine the current distribution of the specimens having different resistivity zones. If the resistance of different areas is known, the flowing current at each part of the specimens can be determined fairly accurately.

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$$I_1 = \frac{E_{corr1} - E_{t1}}{R_1} = \Delta E_1 / R_1 \qquad (4)$$

and

$$I_n = \frac{E_{corrn} - E_{tn}}{R_n} = \Delta E_n / R_n \qquad (5)$$

Therefore:

$$I_{prot} = \frac{\Delta E_1}{R_1} + ... + \frac{\Delta E_n}{R_n} \qquad (6)$$

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

The effect of the corrosion activity on the required protective potential is studied by deliberately increasing the corrosion activity of the coated steelpipe of selective specimens. Corrosion has been activated by polarizing the steel anodically to high positive potential exceeding 2V (CSE). This is achieved upon an application of a maximum of 4V (CSE) external voltage. The effect of prevention, corrosion and protection on the corrosion rate has been examined by an Tafel extrapolation method for specimen AD1. Tafel plots for the three cases are presented in the figure (17). 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.

7. Conclusions

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

1. The results described that the interpretation of potential and current data is an extremely delicated matter. In this respect, the peculiarities of the environment surrounding the steelpipe needs to be fully appreciated including the multi anode effect.

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 provides different information when used for system of different corrosion activity. It is, thus, not a reliable basis for performance evaluation.

3. The cathodic polarization at the dry zone is equal to the anodic polarization at the submerged zone, and the cathodic polarization at the submerged zone equals the anodic polarization at the dry zone. It is found that the externally applied voltage (V_{app}) is equal to the cathodic polarization of the steelpipe minus the anodic polarization of the brass bar anode both at the dry zone. Also (V_{app}) equals the cathodic polarization of the steelpipe minus the anodic polarization of the anode bar both at the submerged zone.

4. The coating resistance cannot, always, be determined from IR-drop value and the corresponding measured external current. Only, when the resistance of the coating is uniform over the entire area that the IR-drop is directly

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proportioned with the resistance through Ohm law.

5. The current decay could be seen as a direct manifestation of the electrochemical change occurring at the steelpipe surface during cathodic protection activation time. The current decay should be described in conjunction with the potential decay.

6. The current measurements can not be relied upon to assess the degree of protection or the amount of current received by different parts of the structure unless reasonably accurate distinction between different anodic areas is established. For this reason, it is not possible to determine the current distribution of the specimens having different resistively areas. If the resistance of different areas is known, the flowing current at each part of the specimens can be determined fairly accurately.

8.References

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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.

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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	.0043	.0088	.005	.012	.0004	.0084	.0025	Rem.

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

Oxide	Content %
SiO_2, Silica	21.6
CaO, Lime	61.2
MgO, Magnesium Oxide	3.6
Fe_2O_3, Ferric Oxide	3.24
Al_2O_3, Aluminum Oxide	5.36
SO_3, Sulfur Trioxide	2.5
Loss on Ignition	1.5
Insoluble Residue	0.5
Main compounds	**% by wt. of cement**
C_3S, Tricalcium Silicate	37.88
C_2S, Dicalcium Silicate	33.35
C_3A, Tricalcium Aluminate	8.2
C_4AF, 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
Sulphate content = 0.05% by weight of gravel as SO_3.		

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Table (5) Sieve analysis of fine aggregate.

Sieve size (mm)	Cumulative percentage passing	Limit of Iraqi Specification No. 45/1984
10	99.3	100
4.75	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
Sulphate content = 0.1% by weight of gravel as SO_3.		

Table (6) Chemical analysis of tap water.

Ions	Concentration (PPM)
Cl^-	156
SO_4^{--}	49
Ca^{-+}	68
Mg^{+}	28
pH value	7.60

Table (7) Protection Current & Corrosion Current.

Testing	I_{corr} (mA)	I_{prot} (mA)
Prevention	0.077	0.163
Corrosion	0.35	-
Protection	0.12	0.7

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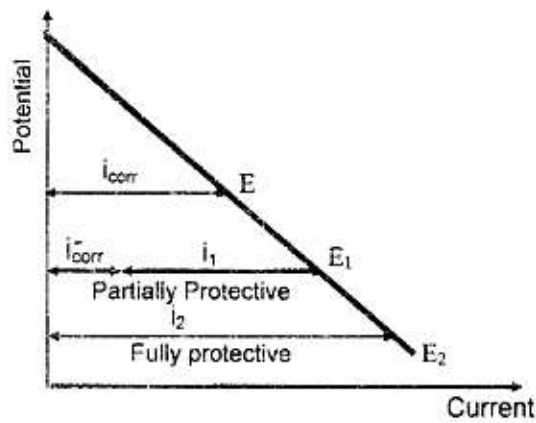
Figure (1) Principle of CP illustrated on a potential-current diagram [1].
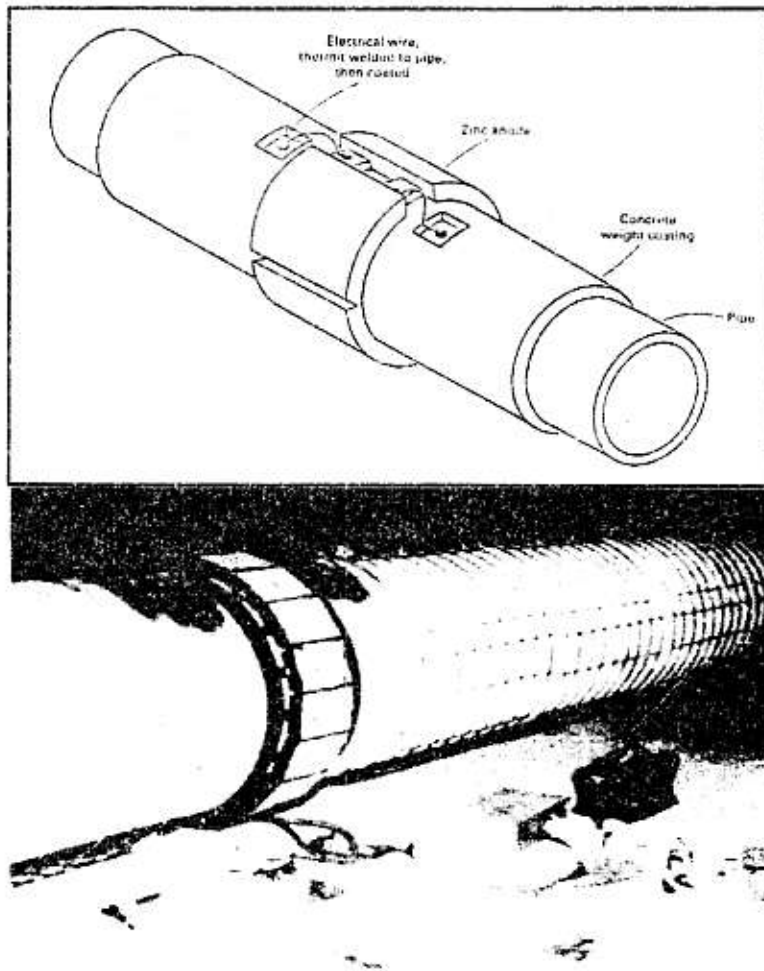
Figure (2) Zinc bracelet anode at a joint in an offshore steel pipeline [9].

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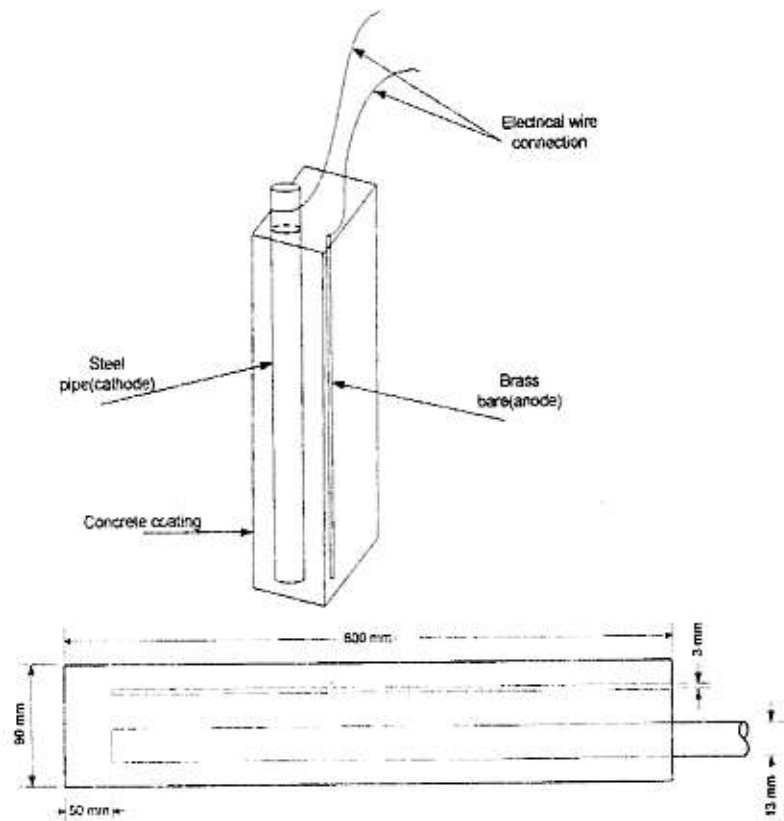
Figure (3) Specimen Details.
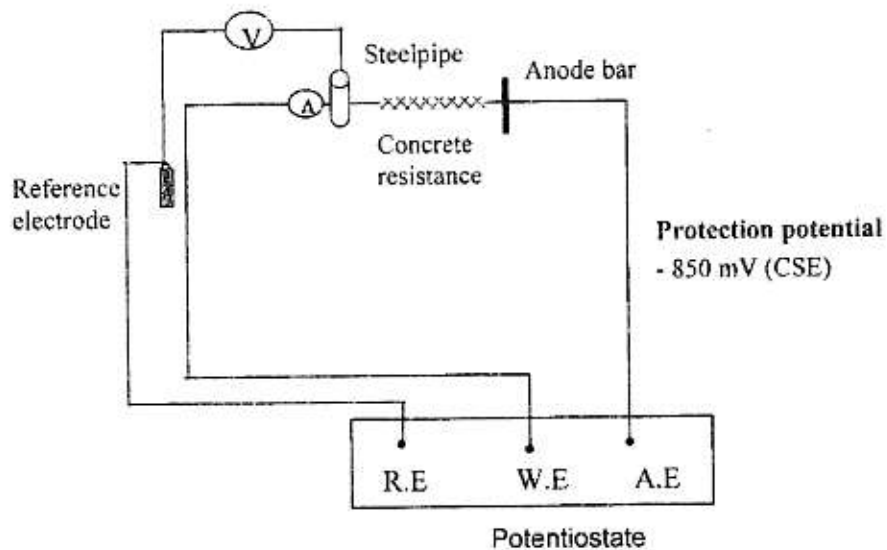
Figure (4) Electrical circuit and test arrangement for potentiostatically
controlled specimens.

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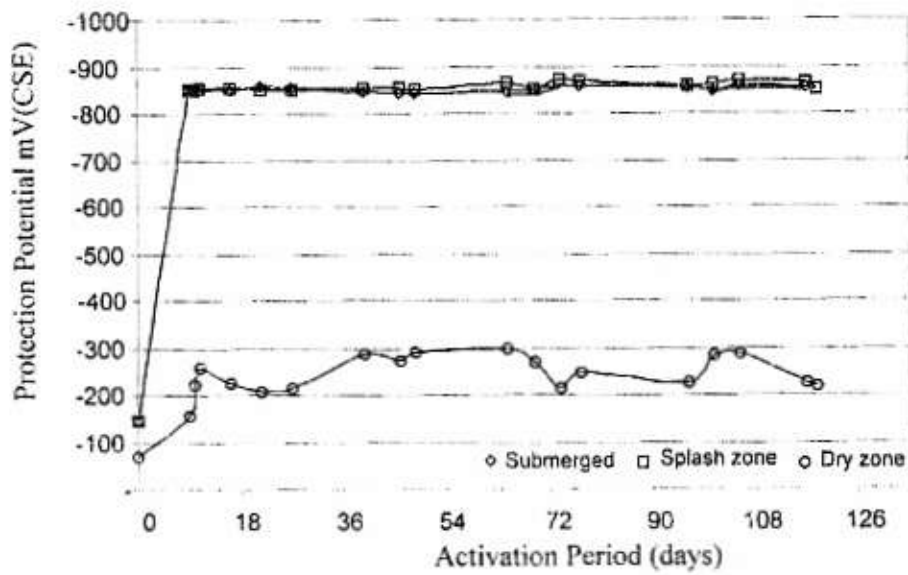
Figure (5) Change in protection potential with time for the specimen AK.
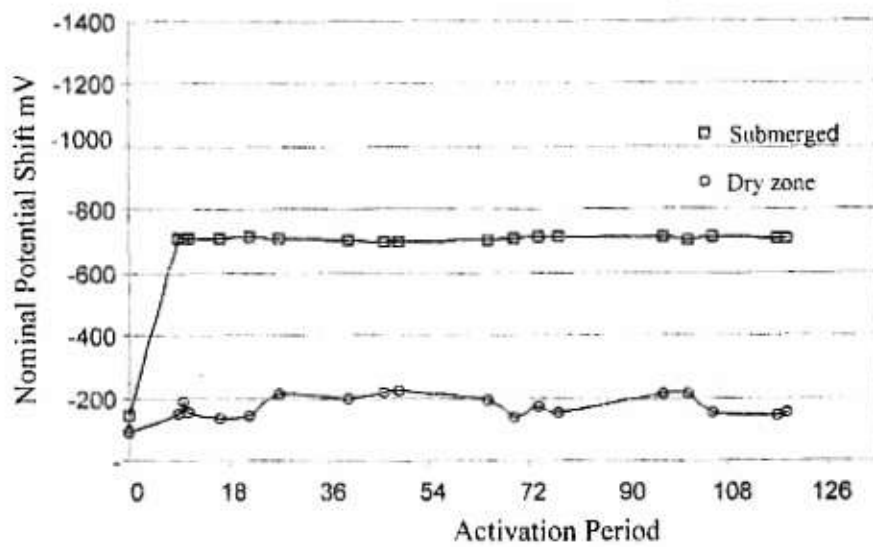
Figure (6) Change in nominal potential shift with time for submerged and dry
zones of the specimens.

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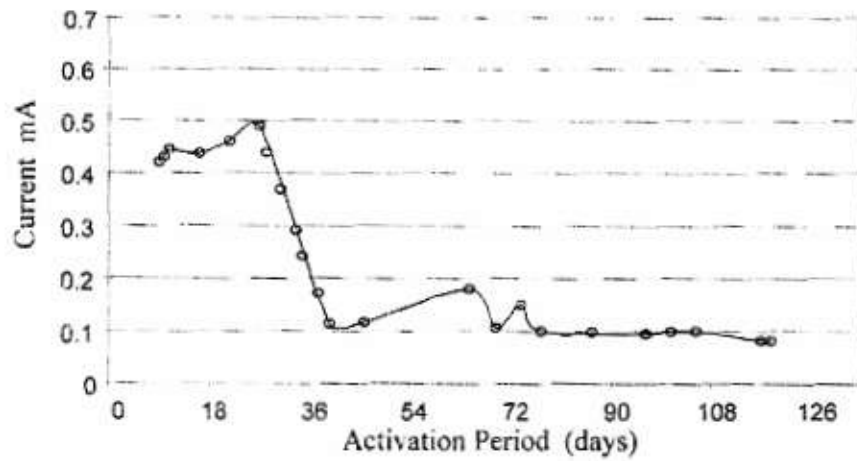
Figure (7) Change in current with time for the specimen AK.
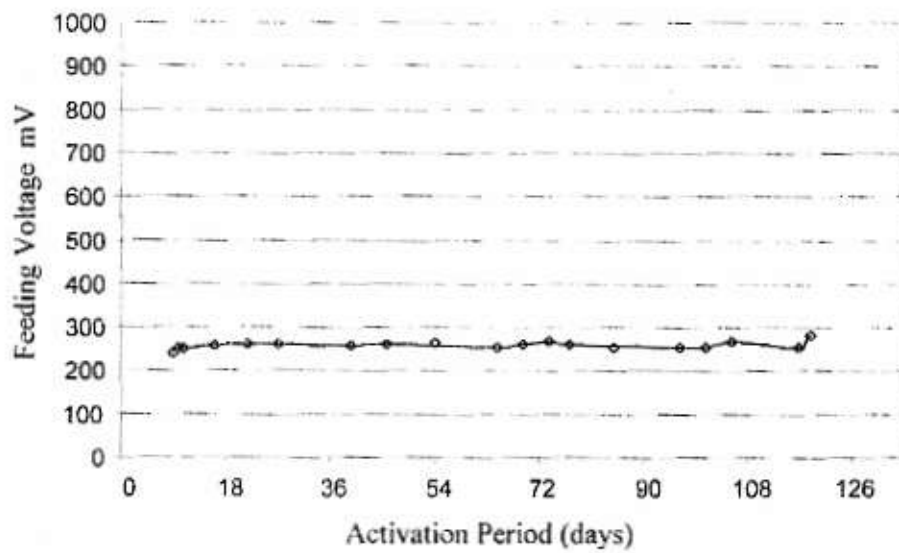
Figure (8) Change in feeding voltage with time for the specimen AK.

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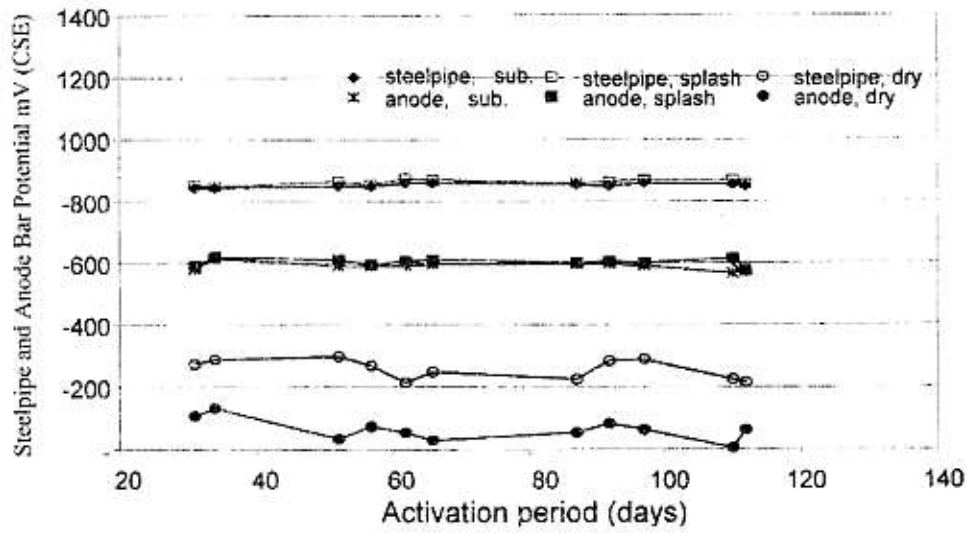
Figure (9) Change in potential with time for steelpipe and the anode bar of the
specimen AK.
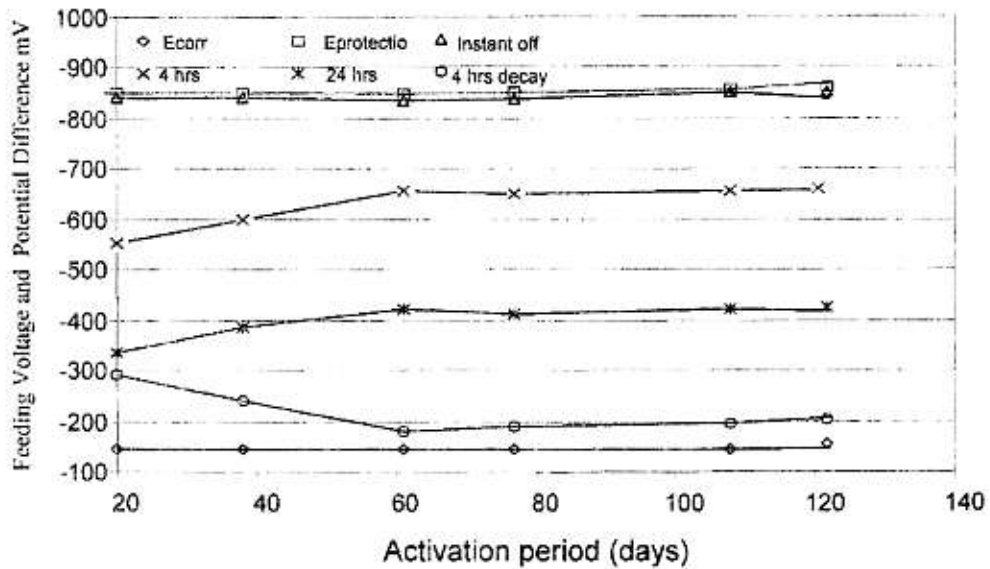
Figure (10) Change in potential parameters for the specimen AK.

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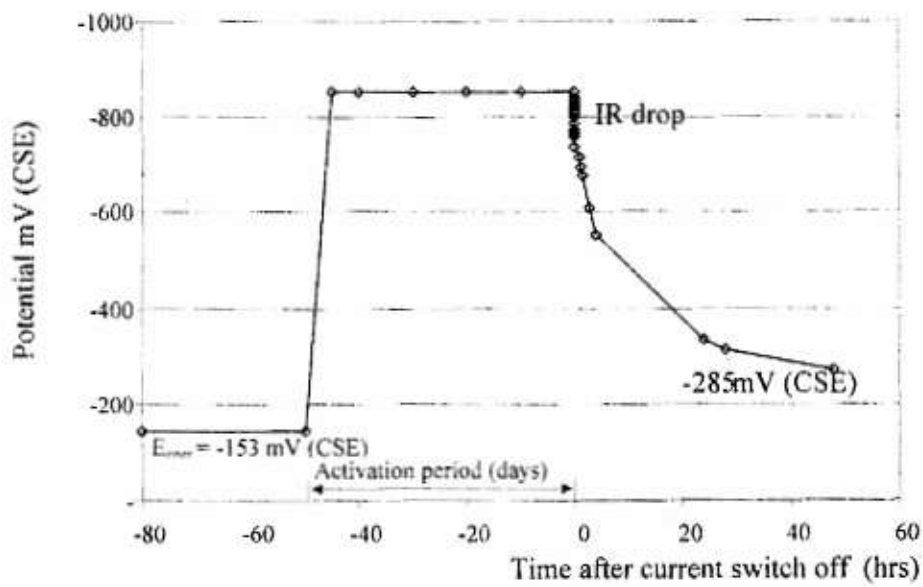
Figure (11) Potential decay curve upon current switch off for specimen AD1.
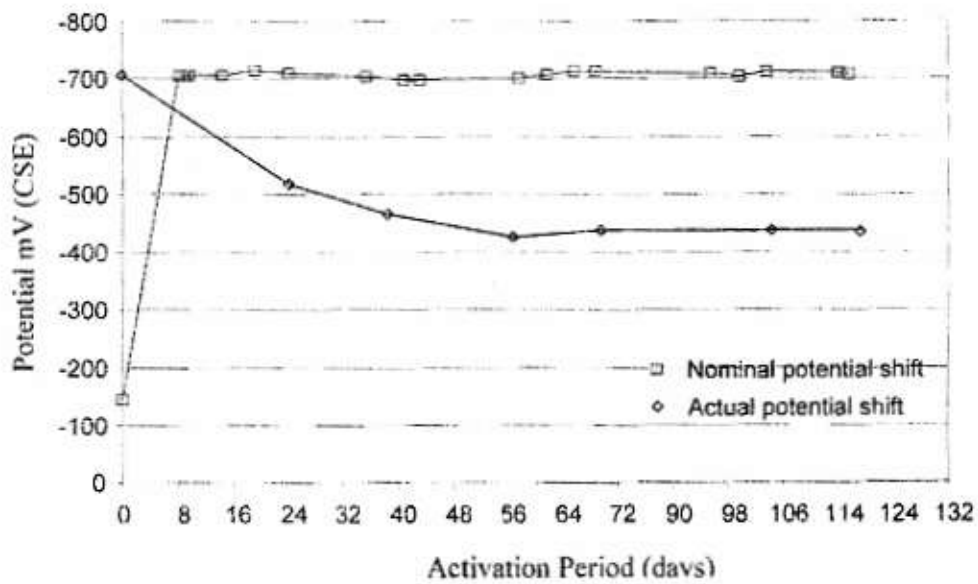
**Figure (12) Change in actual and nominal potential shift for submerged zone
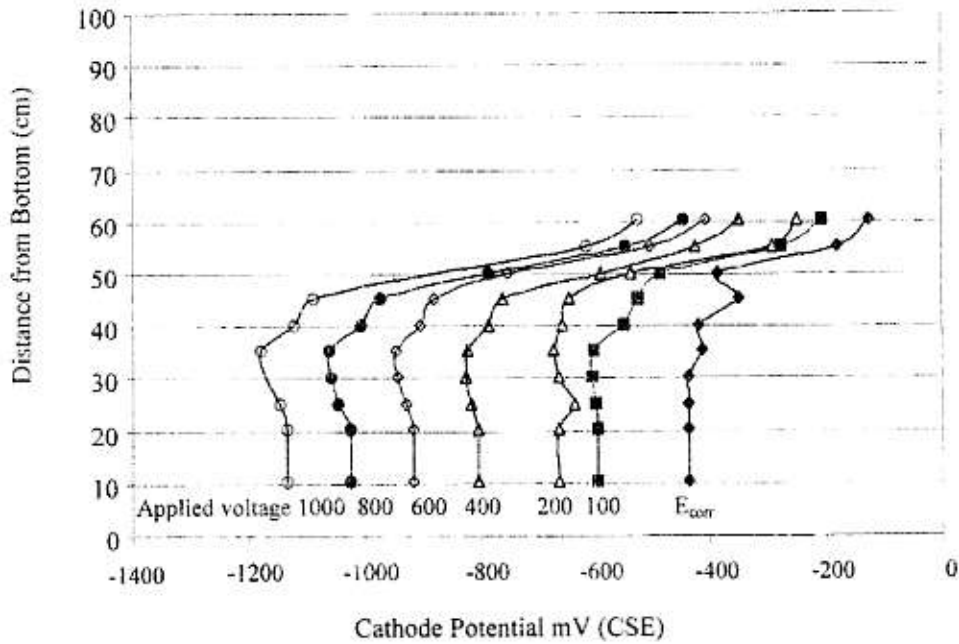of the specimen AK.**

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**Figure (13) Change in potential of steelpipe cathode along the specimen length
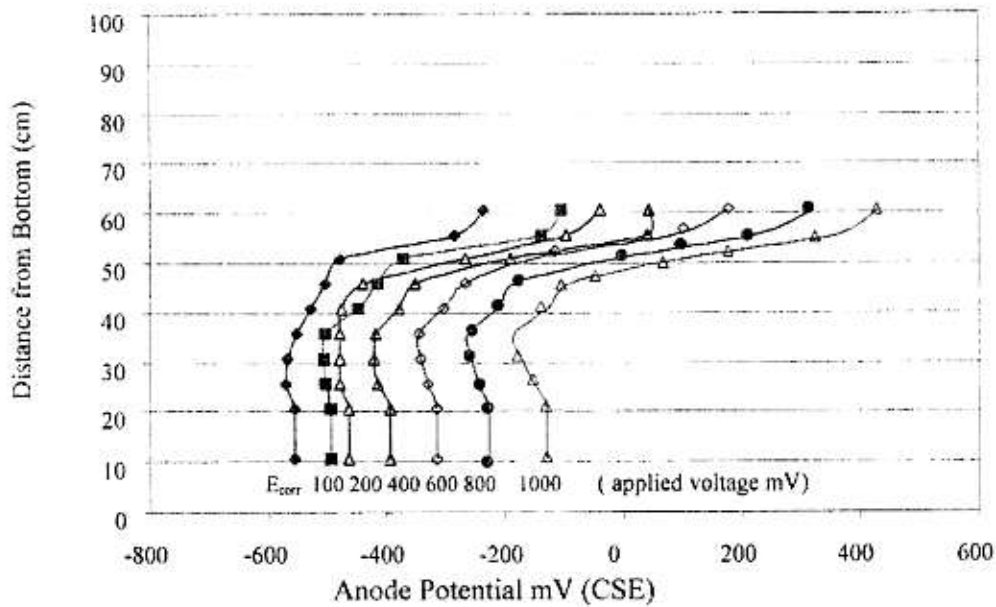with application of voltage AD1.**

**Figure (14) Change in potential of brass bar anode along the specimen length
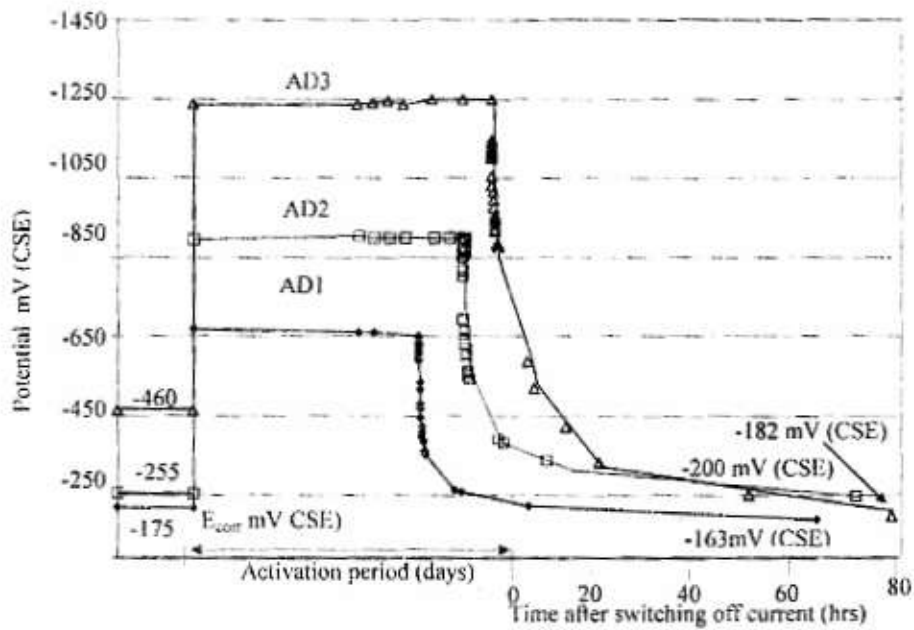with application of voltage AD1.**

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Figure (15) Potential decay curves for the specimens AD1,AD2 & AD3.
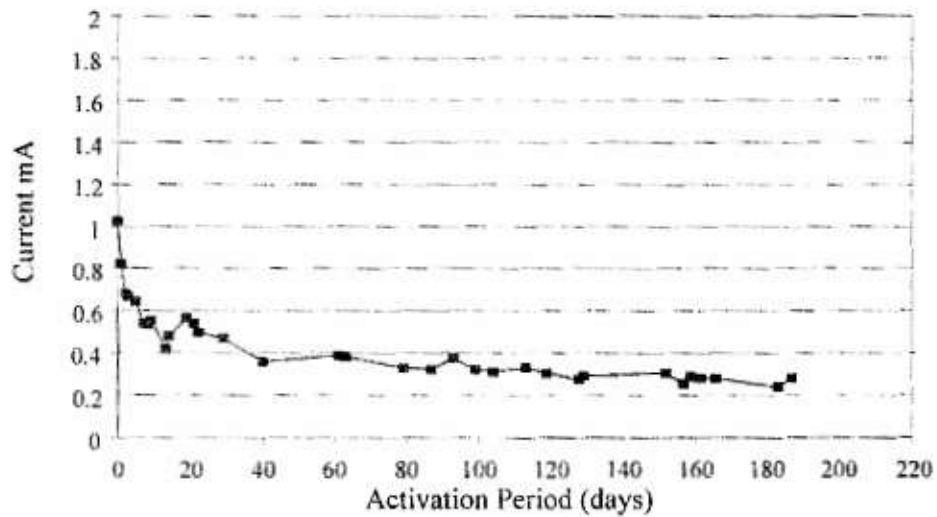
Figure (16) The flowing current for specimen AD1 during activation period.

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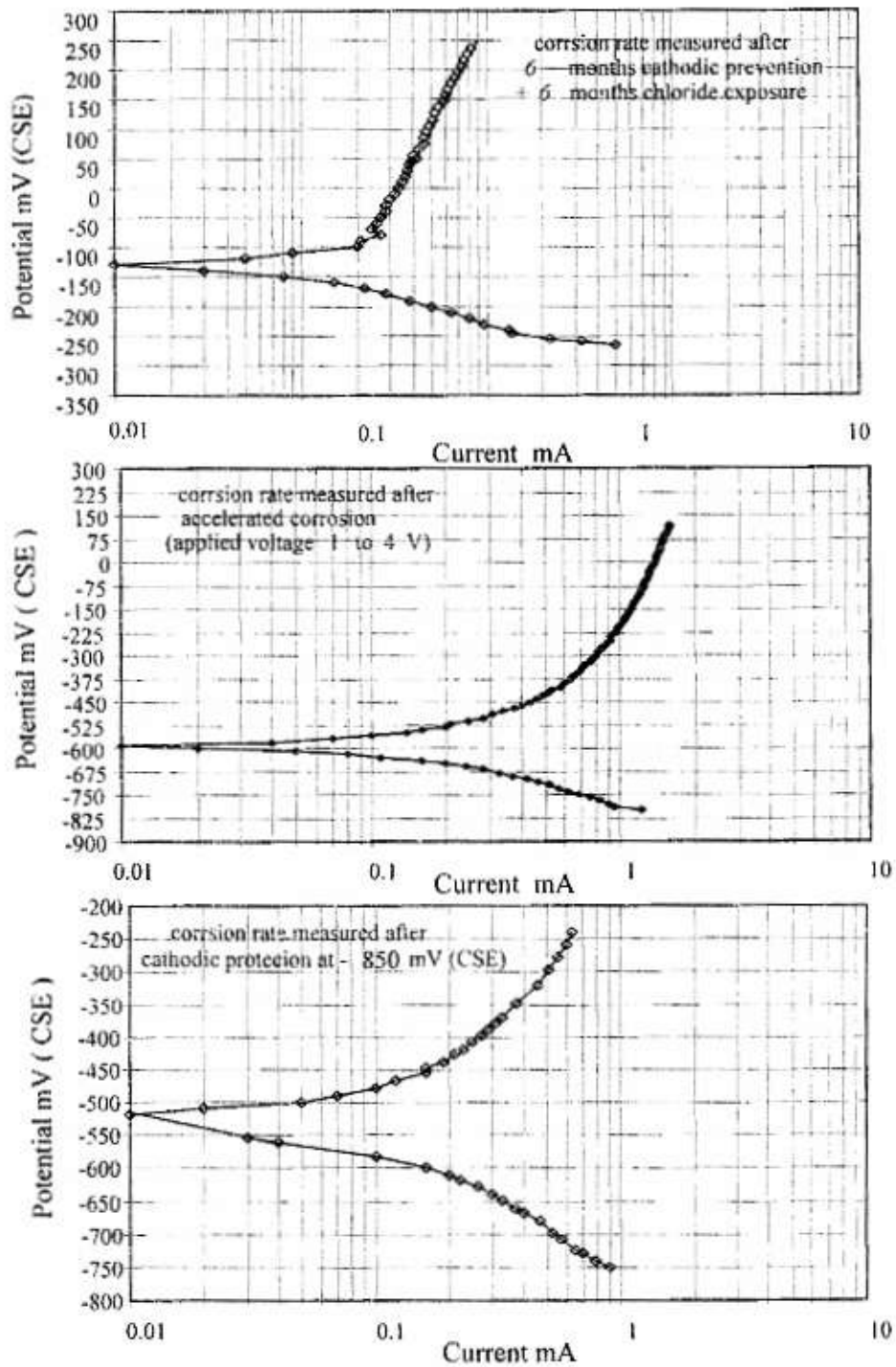Aqueous chloride Solutions by using
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Figure (17) Tafel plots for cathodic prevention, corrosion and CP.