IJCPE
Iraqi Journal of Chemical and Petroleum Engineering

Iraqi Journal of Chemical and Petroleum Engineering
Vol.14 No.1 (March 2013) 25- 37
ISSN: 1997-4884

University of Baghdad
College of Engineering

Simulation of Cathodic Protection System Using Matlab

Naseer A. Al Habobi and Shahad F. Abed
Al-Nahrain University, College of Engineering, Chemical engineering department
, Baghdad, Iraq

Abstract

Iraq has a huge network of pipelines, transport crude oil and final hydrocarbon products as well as portable water. These networks are exposed to extensive damage due to the underground corrosion processes unless suitable protection techniques are used. In this paper we collect the information of cathodic protection for pipeline in practical fields (Oil Group in Al Doura), to obtain data base to understand and optimize the design which is made by simulation for the environmental factors and cathodic protection variables also soil resistivity using wenner four terminal methods for survey sites; and soil pH investigations were recorded for these selected fields were within 7-8, and recording the anodes voltage and its related currents for the protection of underground pipelines.

Modeling enables the designer to build cathodic protection for buried structure and predicting the places of anodes sites and its operating voltages and currents under various operational conditions, and comparing it with those in practices. In this work we compared between the field and simulation results which include, anode numbers, rectifier voltage, rectifier current and anode resistance. The most economical design for the first pipeline was at station no. 2 which need 2.5 A for protection of the pipeline for that specific length and for second pipeline station no. 4 which need 12 A for protection of the pipeline for that specific length.

Keywords

Cathodic protection, pipelines, corrosion, impressed current cathodic protection, cathodic protection system design

Introduction

Cathodic Protection (CP) is a method to reduce corrosion by minimizing the difference in potential between anode and cathode [1]. It is unique amongst all the methods of corrosion control in that if required it is able to stop corrosion completely, but it remains within the choice of the operator to accept a lesser, but quantifiable, level of protection [2]. This work presents a series of studies that examine the design and optimization of cathodic protection systems applied for the protection of buried pipelines. In this work, a general method for predicting the performance of cathodic protection systems and determining the best impressed cathodic protection system design has been presented. In this system, power is drawn from the national grid and converted into a dc current by means of a transformer-rectifier.

From the basic electrochemical theory for absolute protection (zero corrosion rates) is achieved if the structure is polarized to the reversible electrode potential of the anodic reaction. Field experience has shown that in aerated soils mild steel was fully protected at a potential of -850 mV vs. Cu/CuSO4 (-800 mV vs. Ag/AgCl/seawater, +250 mV vs. Zn/seawater and -780 mV vs. SCE). It is important to note that the values quoted for the protection potential refer to the potential difference between the structure and the reference electrode without extraneous effects such as IR drop or field interference. Potentials can vary seasonally as a result of variation in the soil moisture content. Some pipeline companies perform annual surveys at the same time each year, so that trends in the behavior of a pipeline can be properly interpreted [3].

System Description

1. Pipelines

The study of two pipelines made of carbon steel (carbon 0.1649 wt%, manganese 0.5027 wt% , phosphor 0.002 wt%, sulfur 0.0068 wt%, Fe rest)and covered with coal tar coating; the first pipe 52km 0.254in diameter while the second 28km 0.406in diameter. The depth of each pipe is 1.20m.

2. Ground Bed

Ground beds are shallow type installed approximately from (100 - 150) m away from and horizontal to the pipe line in order to obtain suitable spread of current to the line according to the environment conditions. Anode type were used are high silicon cast iron. Ground beds were designed for locations remote from the cathode, allowing low current density transmission across long distances with moderate soil to pipe voltage at the line .In the data based from practices found that the optimum distance of the anode from the pipe is between 100 to 250 m. The depth of ground bed was between (2.5-3) m, their resistance varying from (1.6-0.464) ohm for the first pipe, while the second pipe from (0.929-0.48) ohm. Fifty anodes were used for the 52 km pipeline and twenty five anodes for the 28 km pipeline. In some installations where interference problems are severed, anode beds are sometimes installed deep below the surface. This Causes the current flow to become more vertical and reduces interference between horizontally displaced structures. Deep anodes are also used where the resistivity of the soil near the surface is high. Identified the following desirable properties of an “ideal” impressed current anode material are [4]:

- Low consumption rate, irrespective of environment and reaction products
- Low polarization levels, irrespective of the different anode reactions high electrical conductivity and low resistance at the anode-electrolyte interface. The lowest grounding resistance practically possible should be designed for in order to keep down the electric power and therefore the operating costs [5].
- High reliability
- High mechanical integrity to minimize mechanical damage during installation, maintenance, and service use
- High resistance to abrasion and erosion
- Ease of fabrication into different forms
- Low cost, relative to the overall corrosion protection scheme

3. Soil

A characteristic feature of these desert soils is their lack of homogeneity. A multiplicity of low resistivity salty patches lie scattered throughout a matrix of high resistivity ground. The typical desert soil receives insufficient annual rainfall to carry soluble salts deep into the earth. A great number of salty patches are typical features of desert country, wherever the soil is of clayey nature with some powers of water retention; where the surface consists, however, of loose sandy particles with small water-holding power. The winter rainfalls do not penetrate deeply into the ground in these desert soils afforded by search for water-bearing formations [6]. The major soil or environmental factors that shall be considered for cathodic protection design are:

- Soil resistivity, Soil Resistivity, The resistivity essentially represents the electrical resistance of a standardized cube of material [4].
- PH of soil

Simulation

To design an effective cathodic protection system we should be able to set up test programs, analyzes information acquired from different sources, construct profiles of corrosion problems, suggest operating or maintenance schemes, create test programs for selecting new materials or altering operating conditions, and devise remedial action plans for corrosion problems. For the cathodic protection of the pipeline, the number of the anodes is a very important design factor and playing a very important role, so this factor was optimized to observe the effect on the electric power necessary to keep the metal surface protected. Designing and optimization by utilizing computer programs have been applied primarily to cathodic protection systems in soil. Fig. (1) Shows the simulation using MATLAB software version 7, 2010.

1. Variables Used for the Simulation

Physical properties of the structure to be protected, anode used, soil resistivity, coating type, etc. where used in simulation. Specification used in simulation: [7]

1. Average soil resistivity in ohm.cm.
2. Effective coating resistance at 15 years is estimated at 2500 ohms per square foot.
3. Pipe outside diameter.
4. Pipe length for the specified station.
5. Design life.
6. Design for 2 milliamperes per square foot of bare pipe.
7. Design for 80 to 90 percent coating efficiency based on experience.
8. The pipeline must be isolated from the pump house with an insulating joint on the main line inside the pump house.
9. High silicon cast iron anodes must be used with carbonaceous backfill. Specification about these anodes tabulated in tables 1 through 3.
10. Anode bed must not exceed 2 ohms.
11. Electric power is available at 240 volts AC single phase 50 HZ or three phases from a nearby overhead distribution System.
12. Current requirement test indicates that 2.36 amperes are needed for adequate cathodic protection.

Table 1, Shape functions (K) for impressed current cathodic protection anodes where L is the effective anode length, d is anode/backfill diameter. [1]

L/d	K	L/d	K
5	0.014	28	0.0207
6	0.015	20	0.0213
7	0.0158	25	0.0224
8	0.0165	30	0.0234
9	0.0171	35	0.0242
10	0.0177	40	0.0249
12	0.0186	45	0.0255
14	0.0194	50	0.0261
16	0.0201	55	0.0266

Table 2, Weights and dimensions of high silicon chromium-bearing cast iron anodes [1]

Anode weight (lb.)	Anode dimensions (in)	Anode surface size (in)	Package area (sq. ft.)
12	1*60	1.4	10*84
44	2*60	2.6	10*84
60	2*60	2.8	10*84
110	3*60	4.0	10*84

Table 3, Anode paralleling factors (P) for various numbers of anodes (N) installed in parallel. [1]

N	P	N	P
2	0.00261	14	0.00168
3	0.00289	16	0.00155
4	0.00283	18	0.00145
5	0.00268	20	0.00135
6	0.00252	22	0.00128
7	0.00237	24	0.00121
8	0.0024	26	0.00114
9	0.00212	28	0.00109
10	0.00201	30	0.00104
12	0.00182	-	-

Simulation inputs and outputs tabulated in Tables 4 through 13

Results

A Comparison between simulation results and the field (data based) tabulated below.

For the first pipeline 4 stations (rectifiers) are used while the second pipeline 3 stations (rectifiers) are used. Comparison between the simulation and data based (field) has been achieved, tables and figures below shows these results for these stations.

Pipe area=*Pi*×*D*×*L*

Current requirement= *A*×*I*× *(1-CE)*

$$\text{no. of anodes to meet the anode supplier current density} = \frac{I}{A1 \times I1}$$

$$\text{no. of anodes to meet the design life requirement} = \frac{L * I}{1000 \times W}$$

Total resistance (Rt) =Rc+Rw+Ra

Rectifier voltage= (I) × (Rt) × (150%)

$$\text{Maximam no. of anodes required to meet the groundbed requirements} = \frac{\rho \times K}{L \times (Ra - \frac{\rho \times P}{S})}$$

$$\text{Deep anode groundbed} = \frac{0.00521 \times \rho}{L}(ln\frac{8L}{d} - 1)$$

Rc (structure to Electrolyte resistance)= $\frac{R}{N}$

Rw(the groundbed header cable)= *(ohms/ft)(L)*

Ra(anode ground bed resistance)= $\frac{\rho \times K}{L \times N} + \frac{\rho \times P}{S}$

Where

L	Length of protected structure at specified zone in m
D	Pipe diameter in m
CE	Coating efficiency
I	Required current density mA/m^2
A	Total structure surface area m^2
A1	Corrosion current densitym^2/anode
I1	Recommended maximum current density output in mA
N	Number of anodes
l	Life in year
W	Weight of anode in kg
La	Length of anode backfill column in m
K	Anode shape factor
S	Center to center spacing between anode backfill column in m
Ra	Anode resistance in ohm
Rw	The ground bed header cable resistance in ohm
d	Anode /backfill diameter in m
L_{eff}	Effective anode length in m

Rc	Resistance of cable header in ohm	d_{deep}	Anode diameter in deep anode ground bed in m
L_{deep}	Anode length in deep anodes ground bed in m	V	Voltage
		R	Coating resistance in ohm

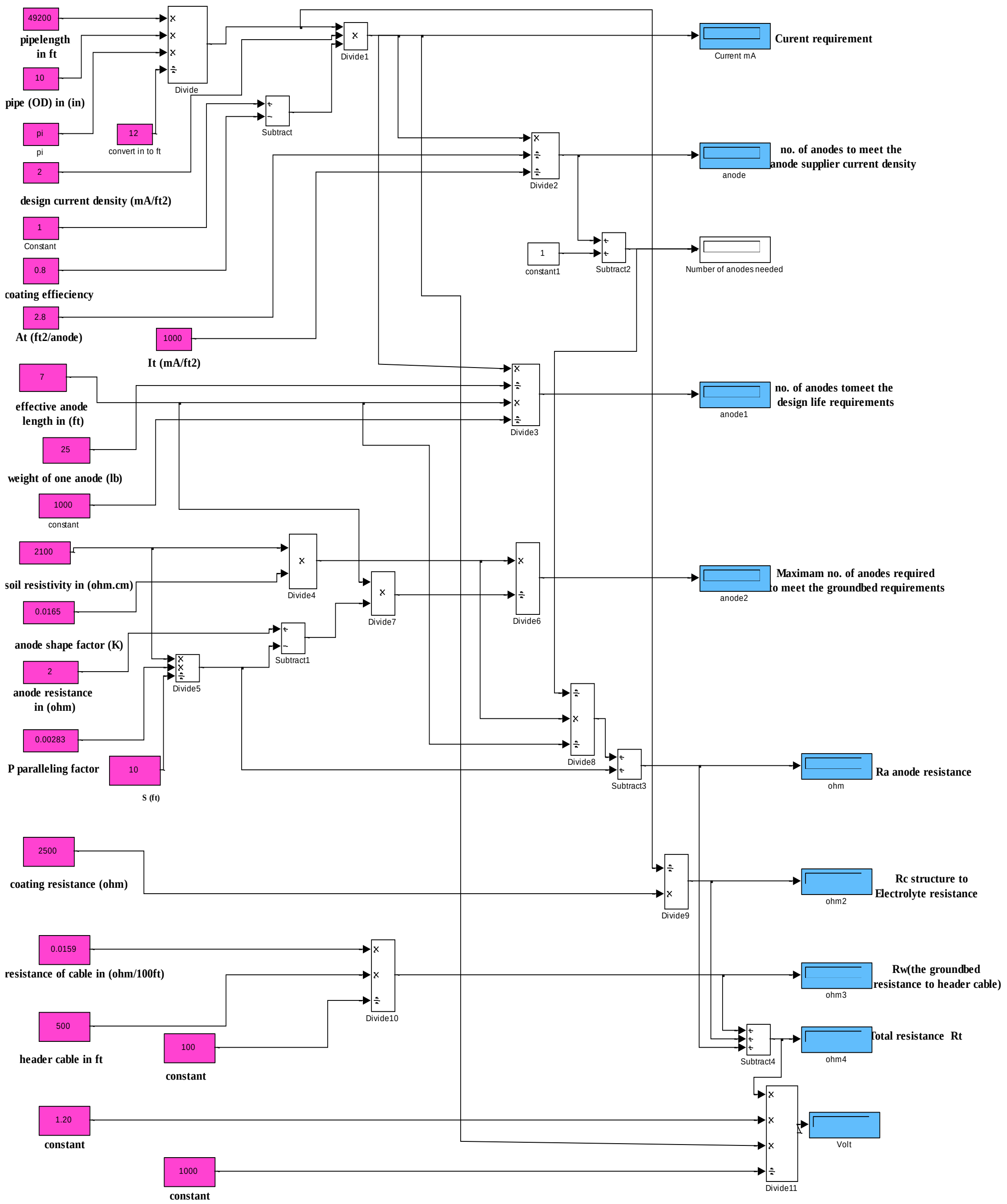

Fig. 1, Simulation using mat lab software

Fig.s (2) and (3) show the pipelines description. Simulation inputs and outputs tabulated in Tables 8 through 15.

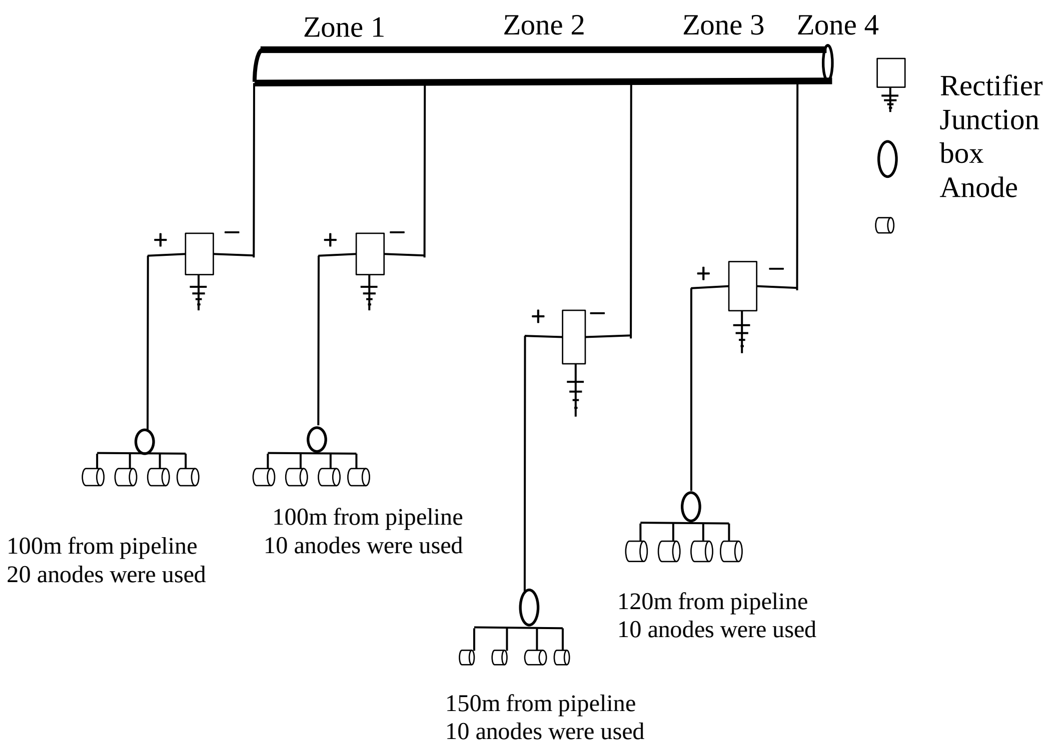

Fig. 2, First pipeline description

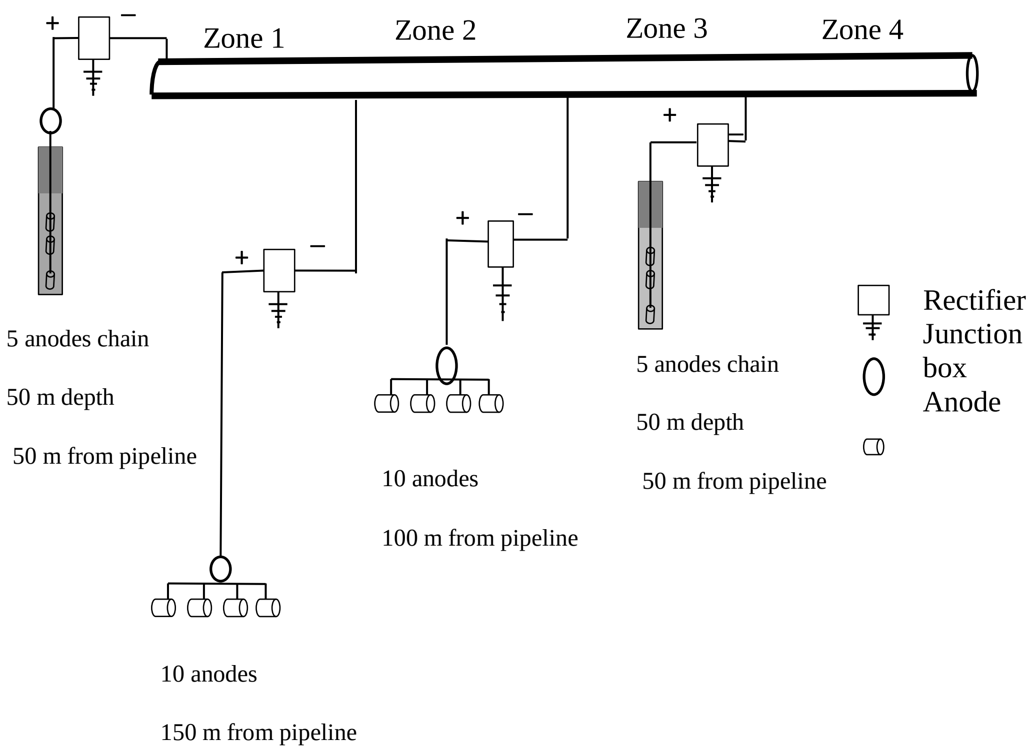

Fig. 3, Second pipeline description

Table 4, the first pipe stations current requirement, voltage; number of anodes

Station no.	Soil resistivity (ohm.cm)	Real (field)	Simulation results	Ra (ohm)
Station 4	1500	12.5A	1.59A	1.6
		7.5V	4.3V	
		10anodes	3anodes	
Station3	1200	4V	12.9V	0.622
		5A	11.9A	
		10anodes	10anodes	
Station2	1000	2.5A	15.9A	0.464
		7V	10.6V	
		10anodes	13anodes	
Station 1	1500	59A	11.9A	1.13
		48V	17.6V	
		10anodes	5anodes	

Table 5, the second pipe stations current requirement, voltage; number of anodes used and need

Station no.	Soil resistivity (Ω.cm)	Real (field)	Simulation results	Ra(Ω)
Station 4	3000	5V	13V	0.68 (deep anode)
		12A	8.9 A	
		5anodes	4 anodes	
Station3	1000	14V	17.2V	0.754
		24A	13.4A	
		10anodes	5anodes	
Station2	1500	13A	17A	0.929
		25V	22.2V	
		10anodes	11anodes	
Station 1	1200	19A	16A	0.48 (deep anode)
		14V	14V	
		5anodes	6anodes	

As given in Tables (6) and (7) the anodes used in each station and the length of pipe that protected by these anodes.

Table 6, first pipeline stations

Station number	Anodes number	Distance between anode and pipeline m	Zone length km
Station 1	20	100	15
Station 2	10	100	20
Station 3	10	150	15
Station 4	10	120	2

Table 7, second pipeline stations

Station number	Anodes number	Distance between anode and pipeline m	Zone length km
Station 1	5 chain 55m depth	50 deep	7
Station 2	10	150	7
Station 3	10	100	7
Station 4	5 chain 55 m depth	50 deep	7

Table 8, Simulation results for zone 1 of the second pipeline

Simulation output		Simulation input	
8939.48	Pipe area m^2	2500	Coating resistance ohm
16091.1	Current requirement mA	7000	Pipe length m
5.74682	No. of anodes to meet the anode supplier current density	0.406	Pipe OD m
1.519	No. of anodes need to meet the design life requirement	17.99	Current density mA/m^2
0.9937	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
0.48	Resistance for deep anode	0.260	At m^2/anode
0.0795	Rw	10758	It mA/m^2
0.02599	Rc	11.36	W kg
0.5832	Rt	25	Life in yaer
14.077	Rectifier voltage V	1200	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 9, Simulation results for zone 2 of the second pipeline

Simulation output		Simulation input	
8939.5	Pipe area m^2	2500	Coating resistance ohm
17879	Current requirement mA	7000	Pipe length ft
6.3854	No. of anodes to meet the anode supplier current density	0.406	Pipe OD in
10.727	No. of anodes need to meet the design life requirement	19.99	Current density mA/sqft
2.244	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
0.7459	Ra	0.2602	At sqft/anode
0.0795	Rw	10758.4	It mA/sqft
0.026	Rc	11.363	W lb
0.8514	Rt	15	Life in yaer
18.267	Rectifier voltage	1200	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 10, Simulation results for zone 3 of the second pipeline

Simulation output		Simulation input	
8939.48	Pipe area m^2	2500	Coating resistance ohm
13409	Current requirement mA	7000	Pipe length m
4.789	No. of anodes to meet the anode supplier current density	0.406	Pipe OD m
1.2658	No. of anodes need to meet the design life requirement	14.999	Current density mA/m^2
1.3728	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
0.7544	Ra	0.2602	At m^2/anode
0.0795	Rw	10758	It mA/m^2
0.026	Rc	11.36	W kg
0.8599	Rt	25	Life in yaer
17.296	Rectifier voltage V	1000	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 11, Simulation results for zone 4 of the second pipeline

Simulation output		Simulation input	
8939.48	Pipe area m^2	2500	Coating resistance ohm
8939.49	Current requirement mA	7000	Pipe length m
3.1926	No. of anodes to meet the anode supplier current density	0.406	Pipe OD m
0.84389	No. of anodes need to meet the design life requirement	9.999	Current density mA/m^2
1.3728	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
0.68	Ra	0.260	At m^2/anode
0.0795	Rw	10758.4	It mA/m^2
0.21186	Rc	11.36	W kg
0.97387	Rt	25	Life in yaer
13.0588	Rectifier voltage V	3000	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 12, Simulation results for zone 1 for the first pipeline

Simulation output		Simulation input	
11972.5	Pipe area m^2	2500	Coating resistance ohm
11973	Current requirement mA	15000	Pipe length m
4.2759	No. of anodes to meet the anode supplier current density	0.254	Pipe OD m
3.3523	No. of anodes need to meet the design life requirement	9.999	Current density mA/ m^2
2.2442	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
1.1316	Ra	0.2602	At m^2/anode
0.0795	Rw	10758	It mA/ m^2
0.0194	Rc	11.36	W kg
1.2306	Rt	20	Life in yaer
17.679	Rectifier voltage V	1500	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 13, Simulation results for zone 2 of the first pipeline

Simulation output		Simulation input	
15963.34	Pipe area m^2	2500	Coating resistance ohm
7981.7	Current requirement mA	20000	Pipe length m
2.8506	No. of anodes to meet the anode supplier current density	0.254	Pipe OD m
6.3854	No. of anodes need to meet the design life requirement	4.999	Current density mA/m^2
2.2442	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
0.9296	Ra	0.2602	At m^2/anode
0.0795	Rw	10758	It mA/ m^2
0.0146	Rc	11.36	W kg
01.0237	Rt	20	Life in yaer
9.8046	Rectifier voltage V	1500	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 14, Simulation results for zone 3 of the first pipeline

Simulation output		Simulation input	
11972.50	Pipe area m^2	2500	Coating resistance ohm
11973	Current requirement mA	15000	Pipe length m
4.2759	No. of anodes to meet the anode supplier current density	0.254	Pipe OD m
9.578	No. of anodes need to meet the design life requirement	9.999	Current density mA/ m^2
1.7035	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
0.6225	Ra	0.2602	At m^2/anode
0.0795	Rw	10758	It mA/ m^2
0.0194	Rc	11.36	W kg
0.7214	Rt	20	Life in yaer
12.955	Rectifier voltage V	1200	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

Table 15, Simulation results for zone 4 of the first pipeline

Simulation output		Simulation input	
1596.33	Pipe area m^2	2500	Coating resistance ohm
1596.3	Current requirement mA	2000	Pipe length m
0.5701	No. of anodes to meet the anode supplier current density	0.254	Pipe OD m
0.1507	No. of anodes need to meet the design life requirement	9.999	Current density mA/ m^2
2.2442	Maximum no. of anodes required to meet the ground bed requirements	0.9	Coating effecincy
1.6031	Ra	0.2602	At m^2/anode
0.0795	Rw	10758	It mA/ m^2
0.1456	Rc	11.36	W kg
1.8281	Rt	20	Life in yaer
4.3775	Rectifier voltage V	1500	Soil resistivity ohm.cm
-	-	2.36	Amp. Needs for adequate cp
-	-	2.13	L effective anode length m

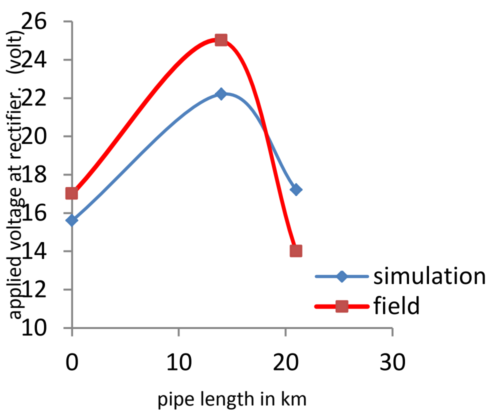

Fig. 4, the difference between field and simulation work for applied voltage for the 28 km pipeline

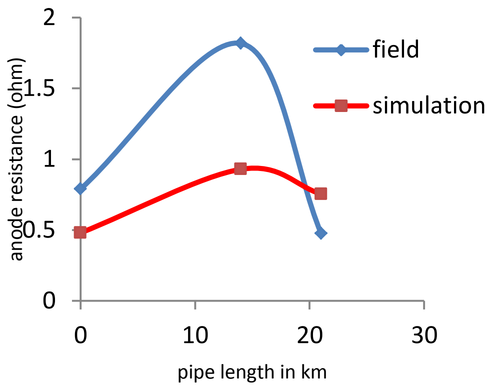

Fig. 6, the anode resistance variation between the simulation work and field for each station for the 28km pipeline

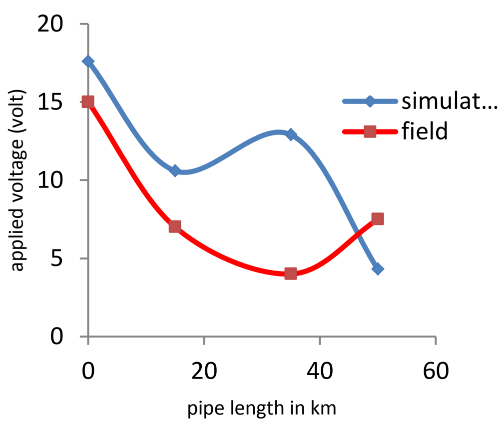

Fig. 5, the difference between field and simulation work for applied voltage for the 52 km pipeline

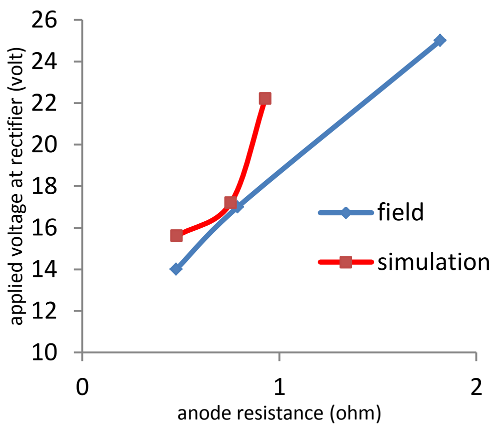

Fig. 7, the relation between the anode resistance and applied voltage for the 28km pipeline

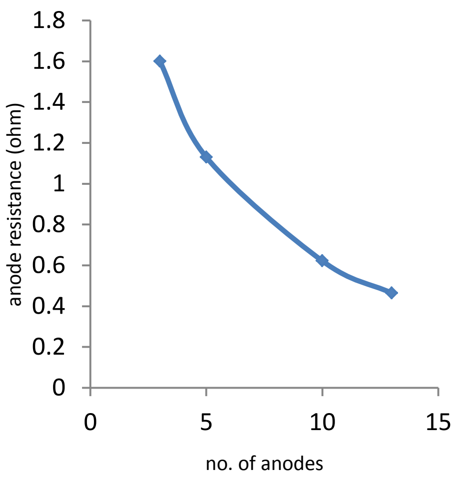

Fig. 8, the relation between the anode numbers versus anode resistance for the 52 km pipeline

Fig. (4) through fig. (8) Show the comparison of between the simulation and field results.

Discussion

- The design of cathodic protection voltage and current is mostly depend on the potential of the pipe, if it is protected this mean that the work is efficient.
- In Fully coated pipe near the pipe or remote it would not make any difference as the coating resistance makes up most of the resistance between the pipe and the soil [7].
- Both the operating cost (power consumption) and installation cost are influenced by the resistance of the anode bed. It is, rather, the one whose resistance is such as to fit into an overall system whose total annual cost is the least, this accomplish with low soil resistivity enhances CP by lowering the anode to earth resistance, thus allowing higher current output for a given voltage [8] High Silicon Cast Iron HSCI *anodes* rely on the formation of a protective oxide film (mainly hydrated SiO_2) for corrosion resistance. The chromium alloying additions are made for use in chloride containing environments to reduce the risk of pitting damage [9]. Casing must be electrically isolated from the carrier pipe; wires on both the pipeline and the casing, the vent can be used instead, there should be difference of anywhere from about 0.25V to 1.0V or more between the pipe to soil potential of the casing has anodes connected to it, the difference may be smaller in that case current pick up or resistance tests between the casing and the pipeline may be required [8].
- The soil pH measured in the field areas was within a range of 7-8 which is slightly alkaline and within those values, soil pH did not indicate soil acidity to be a corrosion factor. From the results of the laboratory and field measurements, it was apparent that any underground metallic piping or structures on the selected sites would be subjected to various resistivity's' environments. Soil varies over short distance of depth, and from season to season. This is often a problem in desert conditions, where the surface can be of extremely high resistivity soil resistivity survey results must always be used with the Wenner method measures average and apparent values.

Rectifier types used depends on the current demand. The current consumption is the lowest when it is uniformly distributed over the pipeline, however. Such a distribution requires too much drainage sites; near the drainage sites the local current densities are several times higher than at the end of protected zone**.** It's also depends on the pipeline geometry, wall thickness, depth of lying. When this maximum current is drained from a point, the pipe to soil potential is a maximum current at the drain point, the resistance of the structure causes the current to decrease nonlinearly as a function of distance from a drain point. A drain point refers to the point on the structure where its electrical connection to the anode is made [9].

The variations and the differences between the total current required for the protection which calculated by the derived equations and those measured during field designing procedure are referred to the high accuracy of the software calculations. The total current calculated from the software was higher than the current applied and measured in the field in some stations, i.e. the total current required for the second pipeline stations 2, 3 and stations 2, 3 for the first pipeline. There was an exception case, where the total current calculated by the model equation was more than the value measured in the field. This exception was recorded when the soil resistivity, the anode resistance, anode numbers values change these three factors change and here is some explanation:

1. As the number of anodes increase the total resistance of anodes decrease
2. The arrangement of anodes is parallel so the current of more than one anode is greater than for one anode for the same rectifier (applied) voltage. this is appear in figure
3. As the anode distance between anode and the pipeline increase the region of pipe to be protected will increase.
4. Current density should be kept low to prevent undue drying out of the soil around the anode as a result of chlorine the localized current density increases and chlorine gas generation also increases in the absence of proper venting this too can lead to premature failure [10].

- 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 the surface of the cathode facing the anode due to the high value of the potential.

Conclusion

- In conclusion, it is believed that in design of an efficient anode system, the proper configuration should be selected, with in the limitations of space and materials available. It is realized that there are no set rules for establishing cathodic protection because there are so many variables and each case must be individually considered. In this light, the foregoing discussion has been presented with hope that it may add to the sum total of previous statements of experiences and recommendations for establishing more efficient systems of cathodic protection.
- This paper shows that the best anode positions was from 50-150 m away from pipeline to give a better protection for the pipeline, and the anode grounded resistance decrease as the no. of anodes increases.
- Additional anodes can be used to achieve a more homogeneous ionic current flow, where an optimum anode-to-cathode separation distance cannot be achieved. Resistivity variations in the

electrolyte between the anode and cathode also have a strong influence on the current distribution. Areas of low resistivity will "attract" a higher current density, with current flowing preferentially along the path of least resistance.

References

1. US Army, *"cathodic protection"* Technical manual, UFC 3-570-02A, 2005, pp. 1-1: F-4.
2. Shrier L.L, R.A. Jarman and G. T. Burstein, *"Corrosion and corrosion control"*, volume 2, 3rd edition, 1993.
3. A. W. Peabody, *"Control of pipeline corrosion"*, 2nd edition, 2001.
4. Pierre R. Roberge, and McGraw, *"Handbook of Corrosion Engineering"* 2000.
5. W.von Baeckmann, W.Schwenk, and W. prinz, "Handbook of Cathodic Corrosion Protection", 3rd edition 1997.
6. W.C.R. Whalley, "*Cathodic Protection in desert soils"*, Corrosion, No.11, vol. 17, 1961, pp559t_565t.
7. Ahmed Z., *"principle of corrosion engineering and corrosion control"*, 2006.
8. 8. Nace international, *"cathodic protection tester course Manual"*. 2007.
9. Roberge P. R., *"Handbook of Corrosion Engineering"*, McGraw – Hill, 1999.
10. Matcor, "*Deep well anode system design*" Technical Bulletin, DW-01, TAH v1.0, 2008, pp.1_9.