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Performance of Cathodic Protection System of API 5L X52 Underground Pipeline

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Abstract: This study highlights the performance of cathodic protection system for buried pipe in different soil environments and explores the experimental results obtained from studying the factors affecting of impressed Current Cathodic Protection system (ICCPs). During the field survey, 4 stations of cathodic protection were studied at different regions along the oil exporting pipeline in Missan City, Southern of Iraq, information was gathered that necessary for designing cathodic protection system. Site conditions were applied on modelling of impressed current cathodic protection the main factors include temperature, moisture content and anode position relative to cathode (pipe) were studied to assess how different variables affected on performance of ICCP system. The advanced statistical techniques employed Response Surface Methodology (RSM) based on Central Composite Design (CCD) was utilized to Design of Experimental (DoE) for ICCP Model. The results of ICCP Model show that the significant factor is moisture content where act on current required for protection. Moreover, the temperature of environment is playing a worthy role in performance of ICCP system, the cathodic current tends to increase as the environment temperature increased. Considered the anode position is a significant factor in pipe-to-soil potential readings. In other hand required current for protection decrease about by 88% for coated pipe rather than being uncoated.

Key words: Buried pipe, corrosion, cathodic protection, Response Surface Methodology (RSM), Central Composite Design (CCD), Design of Experimental (DoE)

INTRODUCTION

Underground pipelines are extensively used in the transportation of liquids and gases around the world. These pipes typically made of low carbon steel that made according to several standards that deal with metallurgical specifications. The most popular among them is American Petroleum Institute (API) standard number API 5L that dominantly governs cross-country pipelines CCP (Chanda, 2013). Although, low carbon steel possesses many favourable properties such as relatively low cost and good mechanical properties, the ease of welding they have a relatively low corrosion resistance in soil (Al-Sultani *et al*., 2016; Varela *et al*., 2015). External corrosion is one of the most common damage mechanisms associated with underground pipelines, several methods are used to reduce and control of corrosion phenomena. Cathodic protection is a mitigation system used to prevent and control of external corrosion in buried pipelines by impressed an electric current from an external source that approximates the current generated naturally between the soil and the surface of the metal during the corrosion process which make the metal surface will be at one potential. There are two type of cathodic protection depending on the source of current. Supply, the first of them is sacrificial anode (galvanic anode) which give current from difference of potential between two metals, the second type consumed the DC current from transformer, solar cells or generator, etc., this method named Impressed Current Cathodic Protection (ICCP), usually utilized with coating to get perfect protection (NACE-SP0207, 2007; Gil *et al*., 2018).

Many studies focusing on cathodic protection for pipelines. Khadim F. Al-Sultani and Jenan Nasser Nabat Al-Sultani and Nabat (2012) studied Protect of underground oil pipelines by using (Al-Sn-Zn) as sacrificial anode in Al-Qasim Region, the researchers showd the relationships between the protection potential with time, sacrificial anode life, discharge currents, taking into consideration the distance between sacrificial anode and protected steel sample. Zedin *et al*. (2016) studied the optimization corrosion protection parameters of steel pipeline by using Taguchi experimental design of three parameters (concentrations of NaCl solution, Temperate

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and Speed of Solution) at three levels (low, medium and high) the research show that the optimum combination of parameters which were reducing the corrosion are temperature (35°C), the speed of solution (15 rpm) and the NaCl concentration (20 wt.%) and the significant factor is NaCl wt.%. Albayati and Alhabobi (2016) studied the modelling of cathodic protection for pipe lines. The study showed that a mathematical model was developed to simulate the ranges of parameters and factors affecting impressed current. Kim and Kim (2001) studied cathodic protection criteria of thermally insulated pipeline buried in soil the study showed the protection potential was shifted to the more negative value as the temperature increased.

The present study aimed to investigate factors (site condition) affecting of impressed current cathodic protection system of API 5L X52 low carbon steel pipelines. These factors include temperature, anode position (distance), soil resistivity (wet and dry) and the pipe situation (coated and uncoated). This experiment was conducted in order to estimate the amount of current required to achieve cathodic protection in environment identical to those that have been studied.

MATERIALS AND METHODS

Experimental procedure: The material used in present study was a segment of pipeline made of low carbon steel type of API 5L X52 in accordance with the American Petroleum Institute specification (API) (ANSI/API Specification for Line Pipe ISO 3183, 2007) (this piece same pipe that used in field) chemical composition analysis of the pipe segment was carried out by metal analysis SPECTRO is shown in Table 1.

Soil temperature survey: The soil temperature of the four sites was measured by the digital the rmometer with two readings per site, first, reading on the surface of the soil and the second, at a depth of 1 m from the soil surface near buried pipe as shown in Table 2. The readings were taken in the Summer season, June.

Moisture test for soil: The site moisture for samples was tested in the laboratory, the soil samples were weighed then dried at temperature of (110°C), a sample allowed to dry for 15-16 h after that dry weight was taken. Calculate the percent moisture as follows:

$$W = [(w1-w2)/(w2-w3)]\times 100$$

Table 1: Chemical composition of pipeline under study

Sample of pipeline	Chemical element (%)
C	0.125
Si	0.254
Mn	1.46
P	0.0143
S	0.0073
Cr	0.0181
Mo	0.002
Ni	0.0108
Al	0.0429
Cu	0.015
Fe	Bal.

Table 2: Temperatures values measured at each site

Site (station)	Temperature°C on surface	Temperature°C at a depth of 1 m
1	51.0	44.0
2	48.3	40.5
3	45.8	37.4
4	43.1	36.4

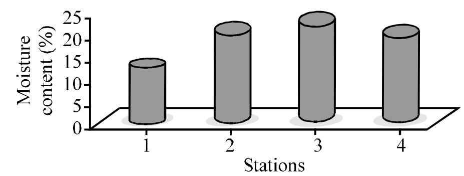

Fig. 1: Moisture content percent for soil samples

Where:
W = Percent moisture
w1 = Mass of original (wet) sample and container
w2 = Mass of dry sample and container
w3 = Mass of container

The moisture content of the samples of the four sites along the transport pipeline in Missan Province showed that the soil have variable values of water content from one region to another as illustrate in Fig. 1.

Modelling of Impressed Current Cathodic Protection system ICCPs: Wooden box was used of dimensions (90×70×50 cm), filled with soil, segment of pipe (cathode) and anode, cathodic protection system was built as shown in Fig. 2. A segment of pipe API 5L type X52 was cut into two identical pieces, each one of (60 cm) length, (2.5 cm) width and (0.6 cm) thickness, both pieces cleaning with emery paper (120-600) grade. One piece was bare and another was coated used in cathodic protection rig of the present study. After that, welded of copper wire at the end of the segment of pipe (cathode) by thermite welding and then coat another piece with polyethylene tap (coating efficiency about 85%). The anode used is scrap steel of 10 cm length, 2.5 cm diameter which is drilled to connect an isolated electrical wire, DC power supply was used to apply voltage likewise current to the

Fig. 2: Model of Impressed Current Cathodic Protection (ICCPs)

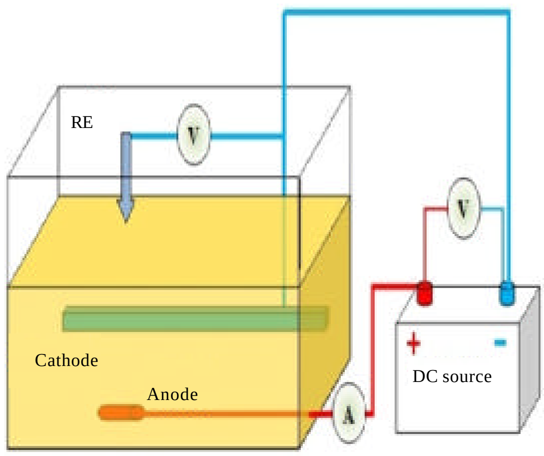

Fig. 3: Sketch of Impressed Current Cathodic Protection (ICCP) connection

model of ICCPs, half-cell of Copper/copper Sulfate $Cu/CuSO_4$ Reference Electrode (CSE) was used for electrochemical measurements.

The purpose of using reference electrode is to determine the potential between the carbon steel pipe (cathode) and the surrounding environment (soil) with different moisture content (10, 15 and 20%) and three levels of temperature (30-50°C) (adopted according to site readings of temperature and soil moisture), a thermal control device used to regulate range of temperature between (30-50°C). The anode was installed and buried in many position. The installation of cathodic protection system was carried out to find the current required and (pipe-to-soil) potential to protect a carbon steel pipe segment which is buried inside the soil box in different types of environment. Figure 3 illustrate ICCP Model connection.

Table 3: Names and levels of factors used to ptimize cathodic protection performance by RSM

Parameters	Designation/units	Coded/actual levels -1	0	1
Anode position	A_P (cm)	15	30	45
Temperature	T (°C)	30	40	50
Moisture content	M (%)	10	15	20

Experimental runs: According to design of experimental DoE a series of runs have been made under different conditions, so that in each run the anode position, moisture content and temperature are specified. At every run the impressed current was recorded likewise potential of (pipe-to-soil) was listed. The potential was read relative to the Copper/Copper Sulfate reference Electrode (CSE) ammeter was used to the reading impressed current. Response Surface Methodology (RSM) based on Central Composite Design (CCD) was selected to design the experiments under three variables in three levels. Choosing the appropriate models and develop of response, surface models been done out through the use of Minitab statistical "Ver.18". Second order regression equation related for responses and variables has been developed using RSM. The parameters and their levels are given in Table 3.

RESULTS AND DISCUSSION

Experimental results are given in Table 4 for current and potential between cathode and soil via. Copper-Copper Sulfate Electrode (CSE) in case of steel pipe was (coated and uncoated) the experiments carried out at a fixed voltage applied. Demonstrate in Table 5 the regression models of statistical optimization set was content three factors (AP, T, M) with three levels in un-coded units of the factors effecting on ICCP system versus each response with the values of the coefficient of multiple determinations that result of relationship between the inputs and outputs was modeled by RSM. The resulting models can be used to predict of current required to achieve protection as well as the pipe-to-soil potential at the particular design points when pipe coated and uncoated.

In order to evaluate the accuracy of regression equations, a validation exercise was carried out, the calculated and the predicted values were plotted against the experimental measurements for all parameters considered in this study by drawing scatter plots that explain the differences between experimental results and predicted results based on these models. Typical scatter plots for all the models are presented in Fig. 4.

Table 4: Observed values for performance characteristics

				Coated pipe		Uncoated pipe	
Run no	A_p (cm)	T (°C)	M (%)	Potential (mV)	Current (mA)	Potential (mV)	Current (mA)
1	45	30	20	-1135	8.0	-1110	59.7
2	15	40	15	-1239	10.1	-1186	86.8
3	30	40	15	-1184	8.7	-1138	63.3
4	30	40	10	-1174	5.8	-1123	42.9
5	30	40	15	-1184	8.7	-1138	63.3
6	45	50	20	-1156	10.3	-1127	91.9
7	30	40	15	-1184	8.7	-1138	63.3
8	15	30	10	-1219	4.3	-1171	36.2
9	15	50	20	-1268	15.1	-1220	163.7
10	45	50	10	-1119	4.6	-1046	34.7
11	30	30	15	-1175	6.5	-1126	48.2
12	30	50	15	-1196	11.2	-1142	88.5
13	15	50	10	-1244	8.9	-1192	58.5
14	45	30	10	-1098	3.0	-1028	20.5
15	45	40	15	-1095	6.6	-1049	51.6
16	30	40	15	-1184	8.7	-1138	63.3
17	30	40	20	-1229	13.0	-1175	119.7
18	15	30	20	-1247	11.4	-1198	95.0
19	30	40	15	-1184	8.7	-1138	63.3
20	30	40	15	-1184	8.7	-1138	63.3

Table 5: Prediction Models for the responses parameters

Responses	Regression predicting model	R^2 (%)
Potential (mv) Coated pipe	$1158+1.90 A_p+6.51 T-11.11 M-0.0699 A_p^2-0.0223 T^2+0.751M^2-0.0633 A_p*T+0.0533A_p*M-0.2400T*M$	98.85
Current (mA) Coated pipe	$-13.71+0.2866 A_p+0.457 T+0.370 M-0.00317 A_p^2-0.00214 T^2+0.0135 M^2-0.00367 A_p*T-0.00433 A_p*M-0.00050T*M$	98.52
Potential (mv) Uncoated pipe	$1291.6-2.177 A_p+0.85 T-18.44 M-0.0717 A_p^2+0.0036T^2+0.615 M^2-0.0067 A_p*T+0.1800 A_p*M+0.0000T*M$	99.53
Current (mA) Uncoated pipe	$-36.0+2.55 A_p+2.90T-8.22 M-0.0097 A_p^2-0.0303 T^2+0.397 M^2-0.0372 A_p*T-0.1127 A_p*M+0.1610 T*M$	98.05

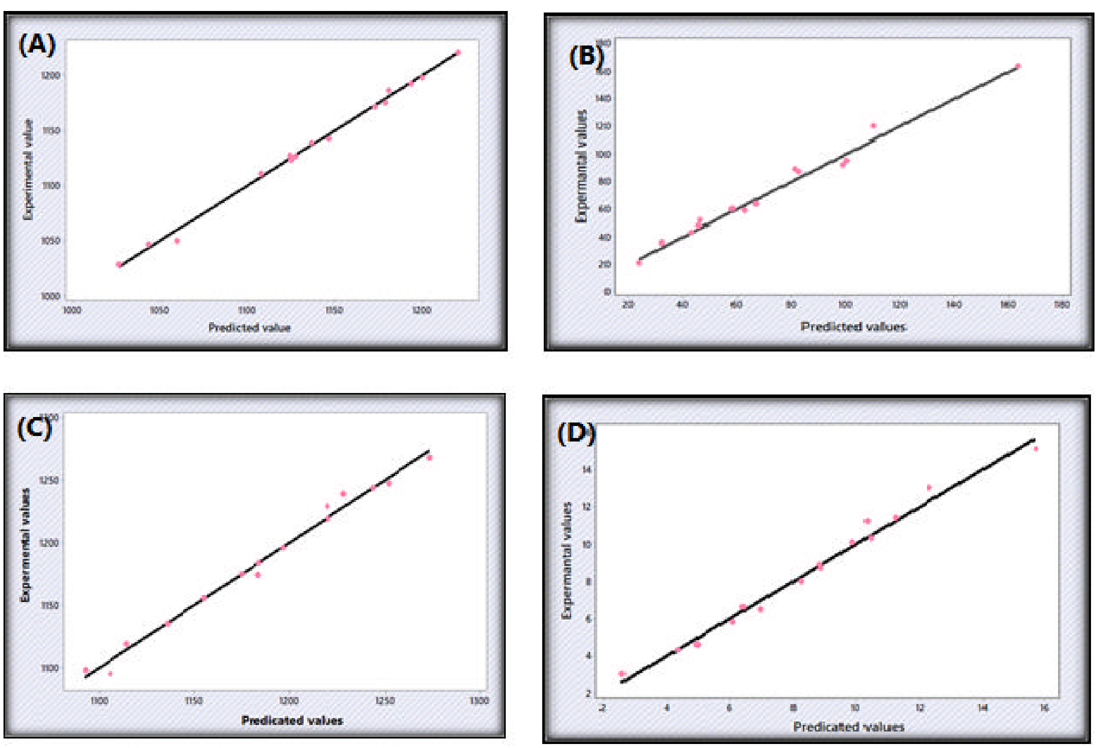

Fig. 4: Scatter plot of experimental values VS predicted values: a) Potential (mV) uncoated pipe; b) Current (mA) uncoated pipe; c) Potential (mV) coated pipe and d) Current (mA) coated pipe

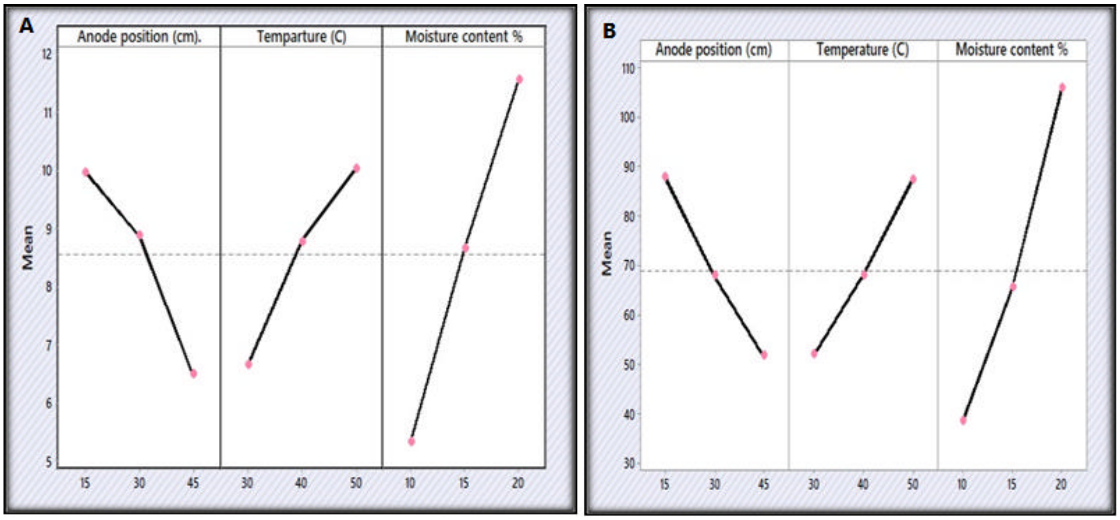

Fig. 5: Main effect plot for current (mA): a) Coated pipe and b) Uncoated pipe

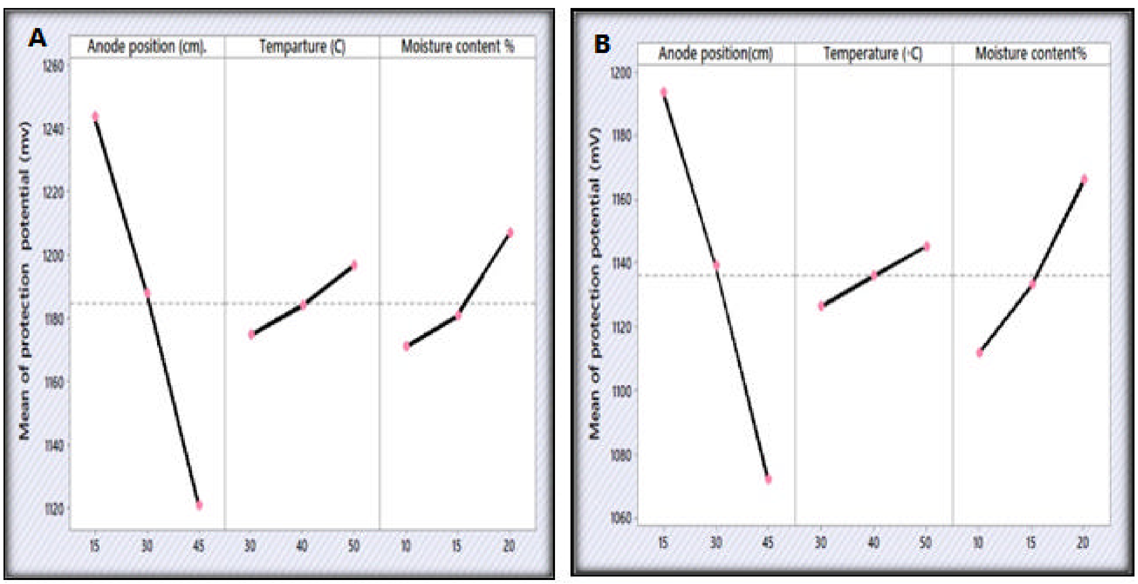

Fig. 6: Main effects plot for potential (mV) (a) Coated, (b) Uncoated

This figure indicates that the developed models, are capable to representing the system under the given experimental domain.

Figure 5 show the main effect plot of each variable on required current for protection in ICCP system in two cases coated and uncoated pipe, respectively. It was found that the current value tends to increase with the increase moisture content by about 124% for coated pipe and about 179% for uncoated pipe. It is clarify the amount of current is directly proportional to the moisture content of soil. The conductivity of surrounding environment is play an important role in corrosion process and cathodic protection system design since, the increasing in conductivity leads to increasing ions and electrons movement causing current flow. From the experimental results as the moisture percentage increased, the cathodic protection current increased. As a result, when conductivity increased (resistivity decreased), the impressed current required for protection also increased this result is agreed with previous study (ANSI/API Specification for Line Pipe ISO 3183, 2007).

As it is evident from Fig. 6, temperature has effect on current magnitude it has increased by about 72.3% for coated pipe whereas increased by about 83.6% for

Table 6: ANOVA results

Sources	df	Seq SS	Adj SS	Adj MS	F-values	p-values
Current (coating pipe)						
Regression	9	161.488	161.488	161.488	74.07	0.000
Linear	3	155.834	155.834	155.834	214.44	0.000
A_P	1	29.929	29.929	29.929	123.55	0.000
T	1	28.561	28.561	28.561	117.91	0.000
M	1	97.344	97.344	97.344	401.86	0.000
Square	3	2.384	2.384	2.384	3.28	0.067
A_P X A_P	1	2.048	1.401	1.401	5.78	0.037
T X T	1	0.024	0.126	0.126	0.52	0.488
M X M	1	0.311	0.311	0.311	1.28	0.284
Interaction	3	3.270	3.270	3.270	4.50	0.030
A_P X T	1	2.420	2.420	2.420	9.99	0.010
A_P X M	1	0.845	0.845	0.845	3.49	0.091
T X M	1	0.005	0.005	0.005	0.02	0.889
Residual error	10	2.422	2.422	2.422		
Lack-of-fit	5	2.422	2.422	2.422		
Pure error	5	0.000	0.000	0.000		
Total	19	163.910				
Potential (coating pipe)						
Regression	9	43431.6	43431.6	4825.7	95.71	0.000
Linear	3	42163.8	42163.8	14054.6	278.74	0.000
A_P	1	37699.6	37699.6	37699.6	747.67	0.000
T	1	1188.1	1188.1	1188.1	23.56	0.001
M	1	3276.1	3276.1	3276.1	64.97	0.000
Square	3	1203.3	1203.3	401.1	7.95	0.005
A_P X A_P	1	168.2	803.3	803.3	15.93	0.003
T X T	1	201.6	5.5	5.5	0.11	0.749
M X M	1	833.5	833.5	833.5	16.53	0.002
Interaction	3	64.5	64.5	21.5	0.43	0.738
A_P X T	1	2.0	2.0	2.0	0.04	0.846
A_P X M	1	60.5	60.5	60.5	1.20	0.299
T X M	1	2.0	2.0	2.0	0.04	0.846
Residual error	10	504.2	504.2	50.4		
Lack-of-fit	5	504.2	504.2	100.8		
Pure error	5	0.0	0.0	0.0		
Total	19	43935.8				
Current (without coating)						
Regression	9	19462.6	19462.6	2162.5	56.01	0.000
Linear	3	17833.2	17833.2	5944.4	153.95	0.000
A_P	1	3305.1	3305.1	3305.1	85.60	0.000
T	1	3157.7	3157.7	3157.7	81.78	0.000
M	1	11370.4	11370.4	11370.4	294.48	0.000
Square	3	291.0	291.0	97.0	2.51	0.118
A_P X A_P	1	19.0	13.1	13.1	0.34	0.573
T X T	1	1.5	25.3	25.3	0.65	0.437
M X M	1	270.5	270.5	270.5	7.01	0.024
Interaction	3	1338.3	1338.3	446.1	11.55	0.001
A_P X T	1	248.6	248.6	248.6	6.44	0.029
A_P X M	1	571.2	571.2	571.2	14.79	0.003
T X M	1	518.4	518.4	518.4	13.43	0.004
Residual rrror	10	386.1	386.1	38.6		
Lack-of-fit	5	386.1	386.1	77.2		
Pure error	5	0.0	0.0	0.0		
Total	19	19848.7				
Potential (without coating)						
Regression	9	47478.1	47478.1	5275.3	236.74	0.000
Linear	3	45018.5	45018.5	15006.2	673.42	0.000
A_P	1	36844.9	36844.9	36844.9	1653.45	0.000
T	1	883.6	883.6	883.6	39.65	0.000
M	1	7290.0	7290.0	7290.0	327.15	0.000
Square	3	993.6	993.6	331.2	14.86	0.001
A_P X A_P	1	224.5	716.1	716.1	32.13	0.000
T X T	1	120.0	0.4	0.4	0.02	0.901
M X M	1	649.1	649.1	649.1	29.13	0.000

Table 6: Continue

Source	df	Seq SS	Adj SS	Adj MS	F-values	p-values
Interaction	3	1466.0	1466.0	488.7	21.93	0.000
A_P X T	1	8.0	8.0	8.0	0.36	0.562
A_P X M	1	1458.0	1458.0	1458.0	65.43	0.000
T X M	1	0.0	0.0	0.0	0.00	1.000
Residual error	10	222.8	222.8	22.3		
Lack-of-fit	5	222.8	222.8	44.6		
Pure error	5	0.0	0.0	0.0		
Total	19	47700.9				

Table 7: Contribution percentage of each factor

	Percentage of contribution (%)		
Responses	A_p(cm)	T (°C)	M (%)
Current (coated)	18.26	17.42	59.39
Potential (coated)	85.80	2.70	7.45
Current (uncoated)	16.65	15.91	57.29
Potential (uncoated)	77.24	1.85	15.28

uncoated pipe. The cathodic current tends to increase as the environment temperature increased. It can be attributed that in buried structures as temperatures increase, the corrosion process is accelerate, ultimately, this leads to an increase in cathodic current to achieve the required protection. In the studied temperature range of 30-50°C, the current increases with increasing temperature this is consistent with another study (Mustafa, 2016).

Contrary to the above, the main effect of anode position displays a reverse tendency. The increase of Anode position (A_P) decreases the current by about 34.6% for coated pipe whereas decreased by about 40% for uncoated pipe keeping the other parameters unchanged, the greater the distance between anode and cathode, the lower of current value. According to the Ohm's law increasing the resistance leads to a decrease in the current value. Finally, the effect of coating can be observed by comparing current values for bare and coated pipe. It is obvious that required current for protection decrease about by 88% for coated pipe rather than being uncoated.

Figure 6 describe the main effect plots of the three variables parameters (input) on potential (output) between cathode and soil with (coated and uncoated). It is comprehensible that the anode position has more influential impacts on potential value. Where the nearest distance between anode and cathode, the high level of protection potential (absolute value), vice versa. The potential tends to decrease whenever the anode further away from cathode and may reach to about 11.6% for coated and the same percentage for uncoated. In conclusion selecting higher A_p results in smaller potential by 11.5% in both cases (coated and uncoated) pipe.

It is understandable from the main effect plot of temperature that potential increases slightly by about 1.7% for coated pipe and about by 1.4% for uncoated. As a result, the potential for low carbon steel is changed with temperature are increased in the negative direction with increase in temperature from 30-50°C. Lastly, it is observed that high level of moisture content lead to increase in protection potential (absolute value) about by 4.6% in both cases (coated and uncoated) pipe. Analysis of Variance (ANOVA) by (Minitab) (Version 18) have been performed to find out the effects of parameters like anode position A_p, Temperature T and Moisture content M on the output parameters, i.e., protection potential and required current during ICCPs operation. Table 6 represents the ANOVA results from these result it is clear to noted that most the quadratic regression models either more significant (p = 0) or significant ($0<p<0.05$), since, p-value is used as a tool to check the significance of each factor, except some of square and interaction value that refer to be insignificant and thus all the models adequately represent the experimental data. Moreover, in this case (ANOVA) was used to determine the percentage of contribution of each factor on the response as shown in Table 7. It can be noted that Moisture content (M) is the most significant parameter relative to current whereas Anode position (A_p) considered the main significant factor in protection potential.

CONCLUSION

Modeling of impressed cathodic protection system for buried pipeline is a good method for predicting the performance of ICCP system with different environmental conditions then the best design has been presented. Coating effect: cathodic protection current (required current) for coated pipe is very low compared with cathodic protection current for bare pipe where the result of experimental showed it decrease by 88% of current consumption if the pipe was coated. Moisture content (M) has greater effect on protection current compared with temperature and anode position. Anode position (A_p) is playing important role in pipe-to-soil readings. The exporting pipeline that passes through Missan Province works in harsh environmental conditions where temperatures rise in the Summer season which extended for a long time in this region of world, making the standard in the cathodic protection system pipe-to-soil potential of -850 mV ($Cu/CuSo_4$) insufficient to achieve the necessary protection from corrosion.

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