FUPRE Journal of Scientific and Industrial Research
Vol.1 (1), 2017
ISSN: 2579:1184 (Print) ISSN:2579-1129 (Online)

Artificial Neural Network Simulation Model for Predicting Oil and Gas Pipeline Corrosion Rate in Nigerian Niger Delta

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Abstract:
This study appraised the significance of all the factors affecting corrosion of oil and gas pipeline in Niger Delta region of Nigerian using artificial neutral network (ANN) technique in order to ascertain the root cause of incessant unexpected pipe failure in this region. Operational and process data of sixty oil and gas transmission pipelines used by six oil and gas companies from 2000 to 2010 for onshore and offshore applications at different oil and gas fields located in this region were sampled and used for both ANN model development and parametric analysis. Results revealed that the predictions of ANN simulation developed in this study which approximates the actual corrosion rates by over 99% are greater than those of conventional De-Waard based simulations presently used by most Nigerian oil and gas companies. Thus, the inadequate prediction of oil and gas pipeline corrosion rate resulting to incessant unexpected pipeline failure in this region. Parametric analysis of the model showed that corrosion rate of carbon steel pipelines used for oil and gas transportation in this region varies linearly with temperature, flow pressure, CO_2 partial pressure, pipe length and pH value while the effects of the pipe age, flow velocity, density, viscosity, chloride sand flow and pipe diameter are non-linear. The used of models/simulations whose predictions are relatively less than the actual corrosion rate of oil and gas pipeline by Nigerian oil and gas companies should be discouraged in order to eliminate catastrophic pipeline failure and its resulting oil spillage/environmental degradation in this region.

Keywords: Artificial Neural Network, Corrosion, Oil and Gas Pipeline, Prediction

Introduction

Pipelines used in oil and gas sector can be made of metallic alloys or plastics but carbon steel pipes remains the best means of transporting oil and gas due to its favourable thermo-mechanical properties(Akano *et al*, 2017). However, apart from design/structural, limitations and mechanical damages that are avoidable, carbon steel pipes used in oil and gas sector are prone to corrosion which is apparently impossible to prevent due to prevailing aqueous environment of this sector(IIman and Kusmono, 2014).Thus, various means of appraisal and prediction of corrosion mechanisms/rate in oil and gas pipeline such as inspection, monitoring and computer modeling techniques are highly valued even though forensic evaluations/mitigation method (coating-painting and cathodic protection) remains an integral part of combating this menace. Although inspections and monitoring using high-resolution magnetic flux, sensors or ultrasonic tools can provide valuable information regarding past and present exposure conditions, these methods can neither predict the remaining life of the pipe nor provide in-depth evaluation of mechanisms of corrosion growth directly except computer or simulation models can do this (Giulia *et al*, 2014).However, unexpected pipe failure and high maintenance cost resulting from replacement of pipes that are not due for replacement still persists in Niger Delta region of Nigeria, despite numerous simulation models developed analyzing oil and gas pipeline behavior under corrosion. This is because none of existing modified De-Waard based simulations used by most oil companies in this region accounts for all relevant variables that influence corrosion of carbon steel pipeline. In addition, some of the simulations considered response variables of pipeline corrosion such as defect depth and length as predictors, thereby hindering analysis/prediction of corrosion rate before the process starts. This adversely affects decision during system design, which results to uncontrollable life cycle cost.

DeWaard and Milliams (1975), modeled rate of oil and gas pipeline corrosion as a function of temperature and CO_2 partial pressure, which was later improved to accounts for flow velocity and diameter of pipe by DeWaard and Lotz (1995). Ossai, (2012) improved on the previous by introducing pH value of the pipe's environment. Nesic *et al.* (2005) is limited to prediction of internal corrosion rate of oil and gas pipes as a function of hydrogen sulphide (H_2S), water entrainment in multiphase flow and corrosion inhibition of crude oil component making it unreliable for holistic management of corrosion in this sector. Also, the neuro-fuzzy model of Akano *et al* (2017), which established corrosion rate as a function of pipe burial depth, soil type, pH, temperature and moisture content is limited lithospheric application. Although, the function developed for predicting corrosion rate of oil and gas pipeline by Norsok (2005), considered the effects of temperature, CO_2 partial pressure, pH and shear stress of the pipe, the temperature range assumed in this work is not realistic in all environment and flow parameters of the fluid transported were not considered. Thus, Iyasele and Ntunde (2016),modified Norsok M-506 algorithm to include the effects of heat capacity, fluid density, fluid velocity, internal diameter, heat transfer coefficient, inlet temperature, surrounding temperature, total pipe length, pipe thickness, system pressure, oil flow rate, inhibitor efficiency, and water volume flow rate without considering effects sand deposits and pipe age. Netto *et al* (2005) and Gatekeeper (2014) showed that sand flow rate increases localized corrosion growth in oil and gas pipeline while Woldeyohannes and Majid (2011) revealed that pipeline age affects its performance. Thus, the high rate of unpredictable pipe failure resulting to incessant accident/loss of life, products wastes, environmental pollution and high operational cost pipeline facilities in this region.

Therefore, the need for the best means of quantifying the combined effects of all the predicting factors affecting oil and gas pipeline corrosion in this region to enable effective assessment of the significance of each predictor's influence on the pipe's corrosion rate as it interacts with others. Most modern parametric investigations such as this that are not easily expressed in a traditional computer algorithm using rule-based programming usually lend themselves to artificial neural network (ANN) modeling because of its outstanding feature of fitting complex nonlinear interactions between systems inputs and outputs (Bassam *et al*, 2009).Although, the recent efforts of Kexi et al (2012), Mohammed et al (2014), Din et al (2015), and others in the development of models for effective prediction of pipeline corrosion rate using ANN technique cannot be overemphasized, none of them comprehensively considered all the predicting factors of this corrosion process in Niger Delta region. In addition, application of model for predicting rate of corrosion in structural steel tower developed by Din et al (2015) is limited because its prediction capability depends on corrosion indicators and precision of measuring devices (defect depth, defect length, width, orientation, and odometer) instead of its origin. Hence, the objective of this study is to appraise the significant of factors affecting corrosion rate of carbon steel pipeline used oil and gas transmission in Niger Delta using artificial neutral network

Methodology

The study involves application of neural network method in fitting a mathematical function relating corrosion rate with all the factors affecting corrosion of carbon steel pipeline used for oil and gas transportation in Niger Delta and using it for parametric evaluation of the factors in order to determine the significance/nature of their effect in this process. Factors investigated includes pipe age (*A*yrs), diameter (D mm) and length (L mm), temperature (T^0C), CO_2 partial pressure (P_{CO2}bar), flow velocity of the fluid (*V* m/s) and sand (SF m/s), fluid pressure (*P* bar),, density (ρ kg/m^3) and viscosity (μ cP), environmental pH (pH) and chloride content (Cl mg/kg). Operational/process data (Table 1 and 2) of sixty pipelines with insignificant data outliers were selected for this investigation. The pipes were used by six oil and gas companies between 2000 and 2010 at different oil and gas fields at Akwa-Ibom, Balyelsa, Cross River, Edo, Delta, and Rivers states of Nigeria. The ANN function/simulation was developed and analyzed using MATLAB2014b from a neural network architecture design (Fig. 1) which uses feed forward and back propagation training algorithms (Fig. 2) for generating and comparing predictions with given/target actual corrosion rates by backtracking and adjusting the weights until the highest possible correlation is obtained. Thereafter, the prediction adequacy/capability of the developed simulation was confirmed by comparing it with the predictions of the conventional simulation used by most oil and gas companies in Niger Delta of Nigeria and measured corrosion rate of the pipe sampled before its parametric analysis using Analysis of variance and contour/surface plots.

Table 1: Process data used for developing the ANN model of oil and gas pipeline corrosion rate

PIPELINE	PIPE LENGTH (mm)	DIAMETER (mm)	PIPE AGE (year)	FLUID TEMP (°C)	PRESSURE (bar)	VELOCITY (m/s)	CO_2 PARTIAL PRESSURE(bar)	PH	CHLORIDE (mg/Kg)	SAND FLOW (m/s)	OIL DENSITY	OIL VISCOSITY
1	211	304.8	6	44	55	2.7	4.5	5.6	34.6	1.673	832.60	24.81
2	45	508	37	67	70	1.2	2.5	3.9	36.5	1.04	818.80	10.73
3	121	609.6	19	69	52	1.02	3.8	3.5	35.9	0.98	817.54	10.00
4	300	400	16	35	64	1.81	6.0	6.4	30.7	0.92	838.18	37.18
5	700	610	29	70	36	1.01	4.6	5.2	36.1	0.58	816.88	9.65
6	500	600	32	69	62.8	0.92	5.4	3.8	35.3	0.45	817.59	10.03
7	60	609	25	55	70	0.82	2.2	5.6	34.7	0.43	825.98	16.28
8	500	192.7	8	35	39	2.85	2.2	5.8	32.9	1.83	838.07	36.95
9	242	406.4	26	67	56	1.85	5.8	3.4	37.1	0.98	818.74	10.70
10	119	914	28	45.5	59	0.98	4.9	5.1	34.8	0.67	831.69	23.36
11	55	305	40	70	60	2.71	5.3	6.4	35.2	2.01	816.98	9.70
12	100	508	30	48	64	1.56	2.5	4.3	36.9	1.02	830.19	21.17
13	1000	225	13	55	40	2.2	2.0	5.24	33.8	1.97	825.85	16.17
14	45	508	41	67	30	1.95	3.4	5.86	37.9	1.04	818.63	10.63
15	60	609	15	53	45	1.08	2.9	5.34	34.3	0.69	827.08	17.42
16	500	192.7	11	45	37	2.92	2.2	5.23	31.7	1.56	831.91	23.71
17	121	609.6	6	70	67	0.76	2.6	3.6	38.7	0.41	817.01	9.71
18	211	304.8	31	45	45	2.62	5.4	5.7	34.5	1.78	831.94	23.76
19	210	304.8	27	66.5	69	1.75	4.3	5.45	34.7	1.08	819.09	10.91
20	250	406.4	8	63	49.5	2.85	3.4	5.67	30.1	1.12	821.09	12.22
21	600	610	18	56	55	1.04	3.2	6.5	35.6	0.63	825.31	15.64
22	400	600	14	69	60	1.68	4.9	5.34	35.9	1.02	817.57	10.02
23	145	609.4	16	67	67	2.32	5.1	5.6	36.8	1.02	818.79	10.72
24	145	406.4	22	70	65	2.85	2	5.23	37.9	1.78	817.01	9.71
25	60	406.4	27	46	53	1.9	2.5	5.12	34.9	1.4	831.36	22.86
26	121	609.6	36	68	70	1.28	3.4	5.24	33.6	1.95	818.21	10.38
27	215	304.8	10	70	54	2.95	2.31	6.2	36.9	1.35	816.96	9.69
28	215	304.8	12	56	46	1.82	2.6	3.5	33.3	1.56	825.27	15.61
29	60	508	40	55	60	1.92	2	5.34		1.08	825.93	16.24
30	1000	225	11	70	43	3.28	5.48	3.54	38.9	1.98	816.91	9.66
31	45	508	39	69	54	2.24	5.2	4.1	36.8	1.22	817.5	10.0
32	45	508	40	30	56	3.5	4.2	3.5	37.7	1.07	841.3	48.3
33	100	508	23	34	70	1.92	3.5	6.45	31.6	1.23	838.8	39.1
34	100	508	26	28	43	3.38	6	3.4	34.9	1.93	842.4	54.3
35	500	192.7	9	70	59	3.4	5.1	4.43	38.5	1.91	817.0	9.7
36	242	406.4	21	45	68	2.8	2.5	5.5	35.12	1.77	832.0	23.9
37	242	406.4	24	43	67	2.58	3.4	5.65	32.76	1.45	833.3	25.9
38	242	406.4	26	38	69.5	2.34	3.7	5.64	33.6	1.24	836.3	32.3
39	242	406.4	28	46	49	1.84	6	4.34	32.9	1.05	831.3	22.8
40	300	400	11	69	53	1.96	5.3	5.34	34.8	0.98	817.5	10.0

Table 2: Process data used for confirming the ANN model of oil and gas pipeline corrosion rate

PIPE-LINE	PIPE LENGTH (mm)	DIAMETER (mm)	PIPE AGE (year)	FLUID TEMP (°C)	PRESSURE (bar)	VELOCITY (m/s)	CO_2 PARTIAL PRESSURE(bar)	PH	CHLORIDE (mg/Kg)	SAND FLOW (m/s)	OIL DENSITY	OIL VISCOSITY
41	300	400	13	67	54	2.48	2.4	6.33	35.5	1.99	832.03	1.07
42	300	400	15	70	56	2.08	3.2	6.43	33.8	1.43	833.06	1.07
43	300	400	17	45	48	2.02	2.3	6.5	32.9	1.78	793.35	0.83
44	300	400	19	65	47	3.02	2.56	5.34	34.2	1.98	846.21	1.06
45	600	610	23	46	58	1.8	3.7	5.31	36.4	1.41	778.94	0.84
46	600	610	25	45	70	1.24	5.1	5.11	36.43	0.76	763.71	0.81
47	600	610	27	54	64	2.14	2.6	6.5	32.12	1.32	789.10	1.00
48	600	610	29	45	67	1.28	2.55	5.34	33.76	0.84	766.32	0.80
49	600	610	31	57	69	1.98	3.2	5.74	34.6	1.05	788.81	1.05
50	45	508	11	67	70	1.52	3.21	5.34	35.3	1.04	804.45	1.12
51	45	355	12	56	35	2.54	3.56	5.4	36.8	1.91	869.29	1.10
52	55	508	11	70	57.4	2.16	5.67	5.2	31.2	1.75	830.09	1.07
53	55	711	8	68	67.5	0.98	5.78	5.19	36.2	0.45	809.41	1.12
54	211	650	7	58	54	2.24	4.2	5.64	34.6	1.54	813.82	1.05
55	211	200	14	67	51	3.42	2.4	5.71	35.5	1.43	839.27	1.06
56	211	400	17	69	49	2.55	2.6	5.7	34.12	1.39	848.60	1.04
57	45	400	8	70	65	2.36	5.76	3.9	35.9	1.01	816.33	1.10
58	60	350	6	65	65	2.46	2.12	5.3	37.6	1.55	808.14	1.10
59	60	700	12	67	68	0.93	2.6	5.23	34.7	0.47	808.55	1.12
60	100	600	7	45	70	1.18	5.67	5.2	33.9	0.59	763.71	0.81

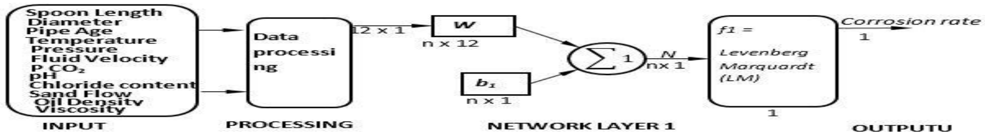


Fig 1: Artificial neural network design for oil and gas pipeline corrosion rate analysis

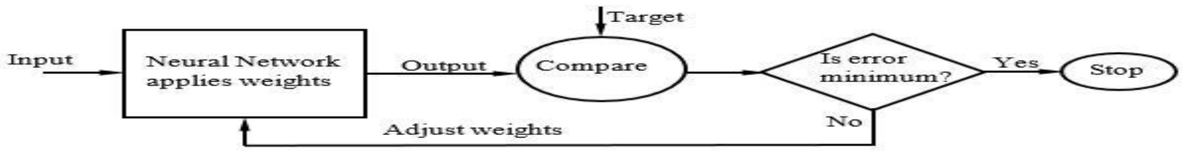


Fig. 2: Flow chart for training the neural network of oil and gas pipeline corrosion rat

Results and Discussion

The user-interfacing window of the developed ANN function (Eqn. 1) computer simulation is shown in Fig. 3. This simulation computes and plots corrosion rate (mm/year) as well as and severity levels of the influence of each parameters on the corrosion rate of oil and gas pipeline. Analysis of this model revealed over 99% prediction accuracy (prediction error range of -0.041 to 0.011%). Also its predictions and the corresponding actual corrosion rates are greater than those of conventional simulation used by most oil and gas companies in Nigeria (Fig. 4).This is anticipated because the conventional simulation used by most companies at present did not account for all the relevant factors affecting oil and gas pipeline corrosion in this region and Analysis of variance of the model coefficients(Table 3) revealed that all the factors investigated contribute significantly to oil and gas pipeline corrosion process. Hence, the perpetual waste of products and environmental degradation as well as accident/loss life due to incessant unexpected oil and gas pipeline failure in this country.

$$\log(CR) = \beta_{11}(K_{1,1}logL + K_{1,2}logD + K_{1,3}logA + K_{1,4}logT + K_{1,5}logP + K_{1,6}logV + K_{1,7}logP_{CO2} + K_{1,8}logpH + K_{1,9}logCl + K_{1,10}logSF + K_{1,11}log\rho + K_{1,12}log\mu + \alpha_1) + \beta_{12}(K_{2,1}logL + K_{2,2}logD + K_{2,3}logA + K_{2,4}logT + K_{2,5}logP + K_{2,6}logV + K_{2,7}\ logP_{CO2} + K_{2,8}logpH + K_{2,9}logCl + K_{2,10}logSF + K_{2,11}log\rho + K_{2,12}log\mu + \alpha_2) + M \quad (1)$$

Where K, α, β and M are constants constituting exponential, transformation, correlation factor, and error correction coefficients respectively.

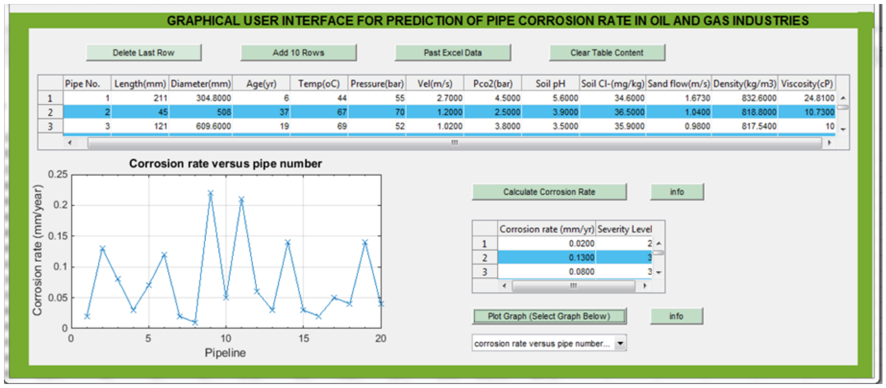


Fig. 3: Main window of the ANN simulation for managing oil and gas pipeline corrosion

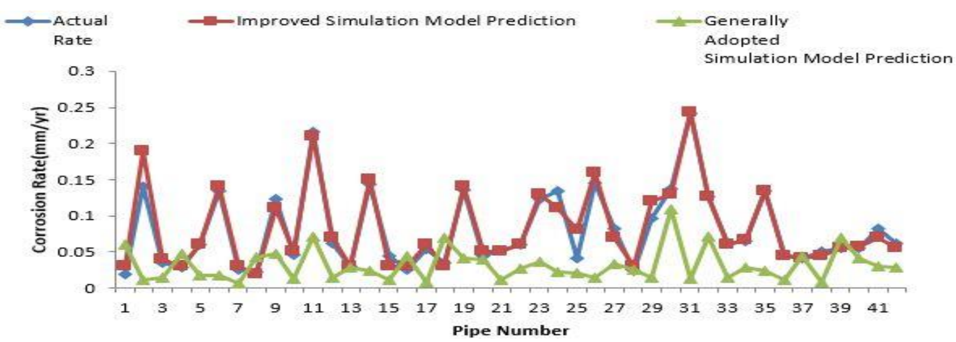
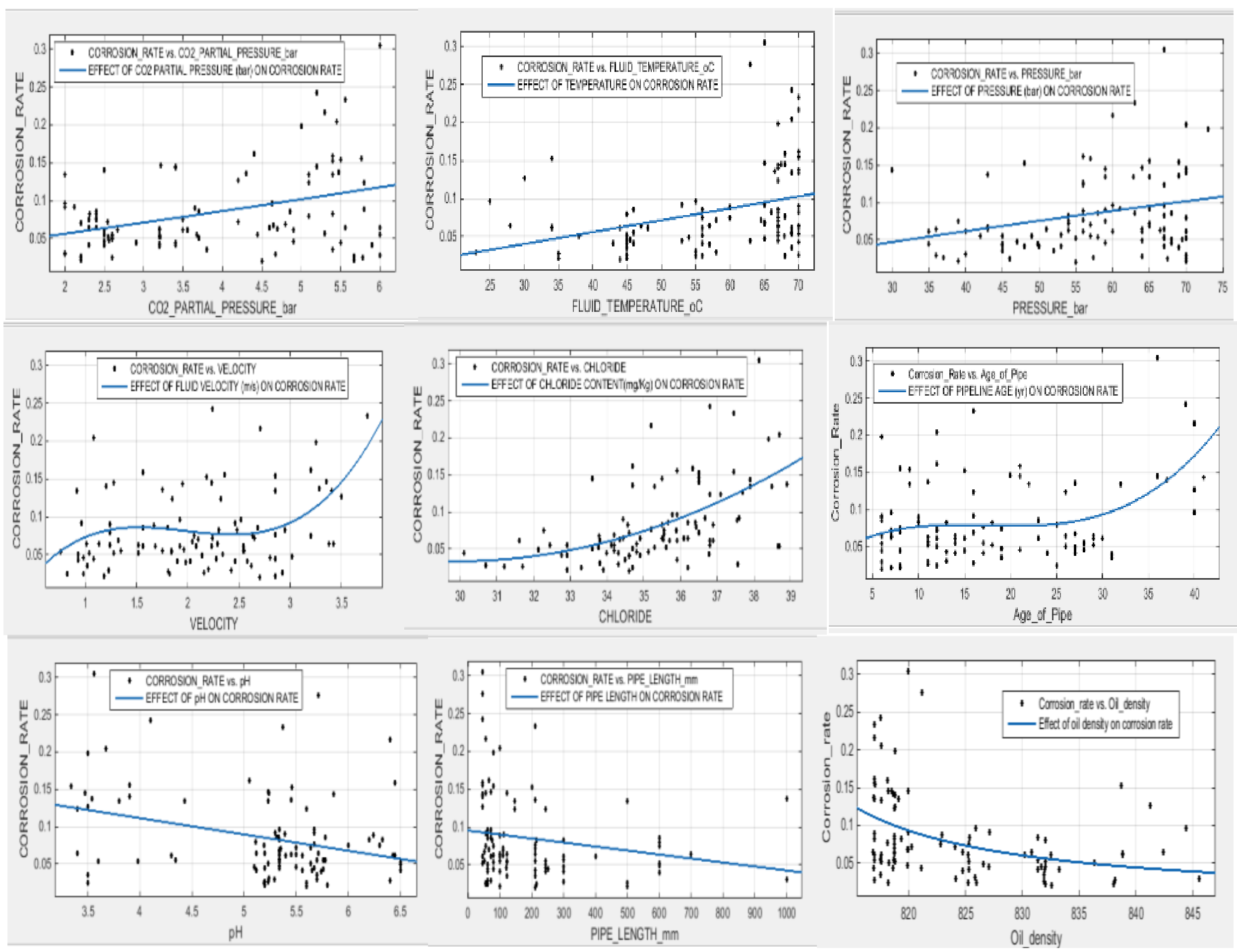


Fig. 4: Comparative analysis of improved simulation for pipeline corrosion rate

Table 3: Analysis of Variance of the developed ANN model parameters

Parameter		Sum of Squares	DF	Mean Square	F	Sig.
Pipe Length (m)	Between Groups	2970202.743	68	43679.452	1.231	.265
	Within Groups	1099920.217	31	35481.297		
	Total	4070122.960	99			
Pipe Diameter (mm)	Between Groups	1674468.863	68	24624.542	1.146	.345
	Within Groups	666309.718	31	21493.862		
	Total	2340778.581	99			
Pipe Age (year)	Between Groups	7306.357	68	107.446	1.660	.061
	Within Groups	2006.633	31	64.730		
	Total	9312.990	99			
Temperature (°C)	Between Groups	10451.975	68	153.706	.949	.582
	Within Groups	5018.297	31	161.881		
	Total	15470.272	99			
Fluid Pressure (bar)	Between Groups	7626.348	68	112.152	1.077	.420
	Within Groups	3228.220	31	104.136		
	Total	10854.568	99			
Fluid Velocity (m/s)	Between Groups	40.779	68	.600	1.357	.176
	Within Groups	13.705	31	.442		
	Total	54.484	99			
CO_2 Partial Pressure (bar)	Between Groups	102.804	68	1.512	.639	.937
	Within Groups	73.316	31	2.365		
	Total	176.120	99			
pH of Pipe Environment	Between Groups	54.344	68	.799	1.625	.069
	Within Groups	15.245	31	.492		
	Total	69.589	99			
Chloride Content (mg/kg)	Between Groups	267.840	68	3.939	1.739	.046
	Within Groups	70.204	31	2.265		
	Total	338.044	99			
Sand Flow (m/s)	Between Groups	16.880	68	.248	1.554	.089
	Within Groups	4.953	31	.160		
	Total	21.833	99			
Density (Kg/m³)	Between Groups	1746865.386	68	2283	1.665	.068
	Within Groups	5666309.187	31	.675		
	Total		99			
Viscosity (cp)	Between Groups	11273692.357	68	122.3	1.498	.079
	Within Groups	1088820.216	31	.741		
	Total		99			

This work also revealed that the rate of corrosion of steel pipes used for oil and gas transmission varies with temperature, flow pressure, CO_2 partial pressure, pipe length and pH value in a linear and uniform trend while the effects of the pipe age, flow velocity, density, viscosity and chloride are non-linear. In addition, the interaction of sand flow and pipe diameter with other factors facilities localized corrosion which causes unexpected failure of oil and gas transmission pipeline than uniform corrosion. The corrosion rate of steel pipes used for oil and gas transmission fairly increase with temperature, flow pressure and CO_2 partial pressure in a uniform trend while density and viscosity of the fluid transmitted reciprocates the effect of temperature reduction as expected. This is because temperature results to contraction (decrease in volume) of the fluid transported which in turn increases its density and viscosity since the speed of the fluid particles reduces as its layers get closer. The rate of corrosion in oil and gas pipeline increased gradually increased gradually to 0.035 mm/yr till flow velocity reached 0.7m/s and remains relatively constant to a velocity of 3m/s before accelerating to average of 0.24 mm/yr. Furthermore, the corrosion rate is partially constant up to chloride value of 31 and slowly increased from 0.03 mm/yr to 0.05mm/yr at 33 before accelerating to an average of 0.17mm/year thereafter. Moreover, corrosion rate of oil and gas transmission pipeline decreases with its length and environmental pH value because oxygen is distributed through the entire length of pipe, thereby reducing its effect on any region as length increases while increase pH value of the environment toward neutrality decreases of ionic/acidic concentration and consequently corrosion and other chemical processes.



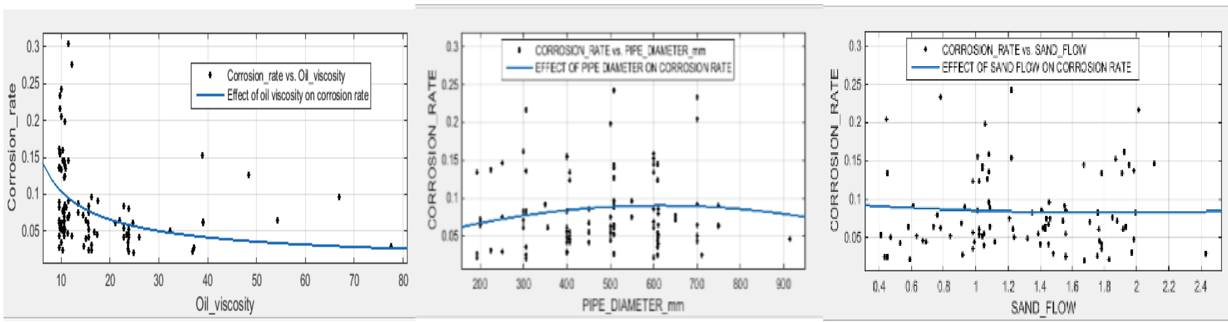


Fig. 5: Parametric effects of the factors on oil and gas pipeline corrosion rate

Conclusion

This study confirmed pipe age, diameter and length, temperature, carbon dioxide (CO_2) partial pressure, flow velocity of the fluid and sand, fluid pressure, density and viscosity, chloride contents and pH value of its environment as the relevant parameters affecting corrosion of oil and gas pipeline in Niger Delta region of Nigeria. Therefore, the inadequate prediction of oil and gas pipeline corrosion rate and the associated incessant unexpected pipeline failure in Nigerian is because the simulation used by most oil and gas companies in this country for prediction and management of corrosion did not account for some of these factors. The use of ANN model developed in this study is therefore recommended to eliminate perpetual waste of products and environmental degradation as well as accident/loss life associated with oil and gas pipeline in this sector

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