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Effect of Thermo Physical Properties Variations on Offshore Platforms Deck Plate Corrosion

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Abstract: This study investigates thermophysical factors that influence corrosion of deck plate of an offshore platform in seawater environment by evaluating the impacts of corrosion indicator parameters on the degradation of the deck plate. In the analysis, the following parameters were measured: deck plate thickness (δ), relative humidity (RH), seawater pH, air temperature (Ta), steel temperature (Ts), dew point temperature (Td), difference in steel and dew point temperatures (Ts-Td) and wind speed (WS) of the seawater environment. The results indicate variations in RH, seawater pH, Ta, Ts, Td, (Ts-Td), and WS over time. Deck plate thickness reduced from 7.8017±0.02mm to 7.7926±0.01 mm after 120 days, representing 0.12% loss in thickness. Mitigation strategies proposed include the use of high-performance protective coatings, cathodic protection systems, careful material selection, and proactive monitoring to prevent crevice corrosion, pitting, and structural degradation.

Keywords: Humidity, temperature, parameters, mitigation, environment, thickness

1.0: Introduction

Corrosion in oil and gas industry presents a significant challenge that can lead to equipment damage, products and financial losses. It can also pose risks to the protection and safety of valuable resources and personnels in the plant. Hence, a comprehensive understanding of corrosion mechanisms and handling of oil and gas systems, from upstream operation tools to downstream operation equipment and processing facilities, becomes imperative to every personnel in the oil and gas sector, particularly the engineers and technical staff. This is crucial for developing effective corrosion prevention strategies and enhancing productivity in the oil and gas industry (Akpan et al., 2023). Various factors, including chemical impurities, operational variables such as temperature, flow rate, wind speed and pressure, can aid the rate of corrosion (Fhadlan et al., 2022). Besides temperature and pressure, other parameters such as in situ pH, fluid dynamics and gas to oil ratio also affect the corrosion of oil and gas facilities (Kadhim and Ali, 2017). Material selection, structural design, galvanic coupling, stray currents and microbes are other important components to consider while designing for corrosion prevention in the oilfield process (Kadhim and Ali, 2017). According to Bolaji et al. (2022), understanding the best operational mechanisms can limit or prevent corrosion arising from improper method and control of process variables. This is essential for ensuring the integrity and efficiency of oil and gas production operations.

There are worrisome corrosion issues in the oil and gas industry, which posed significant challenges to equipment used for operations. The challenges ranged from equipment damage, reduced production capacity, equipment downtime and financial losses to safety risks of personnel in the work environment. The deck plate of offshore platform used for various oil and gas activities on seawater experienced corrosion related issues due to various environmental concerns such as changes in temperature, relative humidity and particulate deposition. Hence, there is need to have comprehensive understanding of corrosion mechanisms and effective handling of oil and gas systems by critical stakeholders in the petroleum industry, particularly engineers and technical staff. This understanding is essential for developing effective corrosion prevention strategies to enhance productivity and safeguard the integrity of oil and gas facilities.

The study aims to investigate the effect of thermophysical properties variations such as dewpoint temperature, temperature difference, relative humidity and wind speed contribute to the corrosion rate of deck plate in offshore platform

2.0: Materials and Methods

2.1 Materials

The following materials were used in the cause of the test analysis: flaw detector ultrasonic testing (UT) machine, connecting cables, thermometer, ultrasonic anemometer, hygrometer, pH meter, stop watch.

2.2 Methods

The methods for testing of corrosion using non-destructive tests were applied in accordance with American Society of Testing Materials (ASTM), particularly in offshore platform (ASTM, 2015). Specifically, the tests were conducted using ASTM E797 standard for ultrasonic testing of materials.

2.3 Procedure for Non-Destructive Test

The test procedures for measurement of corrosion using non-destructive test are stated according to ASTM E797 standard practice for ultrasonic testing of materials (ASTM, 2015). The tests were carried out on the deck plate on a platform located in the Niger Delta region of Nigeria. First, visual inspection was conducted on the deck plate surface and joints to identify any visible signs of corrosion, such as discoloration, pitting, or scaling. A high-intensity light source and magnifying tools were used to inspect hard-to-reach areas for corrosion damage.

Flaw detector Ultrasonic testing (UT) machine was used to measure the thickness of the plate. This was done by calibrating the ultrasonic thickness gauge to required standard. This ensures the accuracy of the thickness measurement. The probes (T-R probe), with specifications: 0-degree MHZ twin Crystal 15mm to 12mm diameter, was used to measure the thickness of the deck plate. It scans defect in base metal. Before, the scanning analysis, the deck plate surface was prepared. Thus rust, loose scale, notches, and grooves on the deck plate surfaces were removed to avoid interference with the probe coupling. The test surface was made to reduce waviness such that no gap greater than 0.5 mm exist between the probe and surfaces. The area was extended to the full distance and it was made free of any irregularities, which may hinder the scanning pattern or cause confusion in the interpretation of the results. The scanning was allowed to reach 100%, while the entire volume was examined with a 10% overlap of the probe.

The equipment was calibrated using a straight beam probe for a suitable range for the thickness of material being examined. A minimum of two back wall echoes from the material under test was noted before taken reading during the examination. The gain control was adjusted to produce a response of 80% full screen height and the screen marked. Then the probe was re-positioned to give the maximized response. At each maximized position, the position of maximum response on the screen was marked. The tests were performed every 30 days from March to July, 2025. After the measurement, the plate thickness loss was determined for each month of the analysis, while the corrosion rates were determined from the measured thickness. The simple mathematical expression for estimation of corrosion rate from the experimental measurement is given in equation (1).

$$Corrosionrate\ (\frac{mm}{day}) = \frac{Changeinthicknes\ (mm)}{time\ (day)} \tag{1}$$

Temperature was measured using calibrated thermometer. The steel temperature was measured by ensuring intimate contact between the steel plate surface and the thermometer, while the air temperature was measured without allowing the thermometer to make contact with any object. The measurement was taken in triplicate to determine the deviation among the measured data. The pH of the water was measured using pH meter with appropriate calibration.

3.0: Results and Discussions

3.1 Relationship Between Deck Plate Thickness Loss and Environmental Factors

The relationship between deck plate thickness depreciation and corrosion indicator parameters were establish by fitting the measured parameters to linear- and quadratic-calibrated mathematical equations in Microsoft Excel. This is to determine the best model that interprets the relationship. The associated environmental factors evaluated include relative humidity, saltwater pH, air temperature, steel temperature, dewpoint temperature, steel-dewpoint temperature different and wind speed. The impact of plate-dewpoint temperature different, relative humidity and wind speed on the corrosion rate of deck plate.

The R^2 value, ranging from 0 to 1, indicates the proportion of the variance in the dependent variable (deck plate thickness loss) that is predictable from the independent variable(s). A higher R^2 value signifies a better fit of the model to the data, and the equation has high accuracy in explaining the observed variation.

Table 1: First Test Results of Corrosion Indicators on Offshore Deck Plate

Test Parameter	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**
Nominal thickness of deck plate (mm)	8	8	8	8±0.00
Current thickness of deck plate (mm)	7.8127	7.7809	7.8115	7.8017±0.02
Relative humidity (%)	65.73	66.60	67.44	66.59±0.85
Seawater pH	7.71	7.69	7.73	7.71±0.02
Air temperature (°C)	30.76	30.97	30.94	30.89±0.09
Steel temperature, Ts (°C)	32.02	30.98	31.23	31.41±0.44
Due point temperature, Td (°C)	26.35	26.23	26.08	26.22±0.11
Δ (Ts - Td) (°C)	5.67	4.75	5.15	5.19±0.38
Wind speed (KNOT)	13.07	13.14	13.15	13.12±0.04

Table 2: Deck Plate Analysis of Corrosion Indicators After 60 Days

Test Parameter	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**
Nominal thickness of deck plate (mm)	8	8	8	8±0.00
Current thickness of deck plate (mm)	7.7892	7.7962	7.8008	7.7954±0.01
Relative humidity (%)	73.67	72.06	71.02	72.25±1.34
Seawater pH	8.05	8.06	8.04	8.05±0.01
Air temperature (°C)	29.06	28.96	29.22	29.08±0.11
Steel temperature, Ts (°C)	29.57	29.52	29.59	29.56±0.03
Due point temperature, Td (°C)	25.14	25.18	25.19	25.17±0.02
Δ (Ts - Td) (°C)	4.43	4.34	4.4	4.39±0.04
Wind speed (KNOT)	11.45	11.27	11.21	11.31±0.12

Table 3: Deck Plate Analysis of Corrosion Indicators After 120 Days

Test Parameter	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**
Nominal thickness of deck plate (mm)	8	8	8	8±0.00
Current thickness of deck plate (mm)	7.7871	7.7922	7.7983	7.7926±0.01
Relative humidity (%)	78.97	79.23	79.28	79.16±0.17
Seawater salt pH	8.26	8.29	8.27	8.27±0.02
Air temperature (°C)	26.04	25.98	26.07	26.03±0.04
Steel temperature, Ts (°C)	26.28	26.33	26.35	26.32±0.03
Due point temperature, Td (°C)	22.65	22.63	22.64	22.64±0.01
Δ (Ts - Td) (°C)	3.63	3.7	3.71	3.68±0.04
Wind speed (KNOT)	9.07	9.06	9.08	9.07±0.01

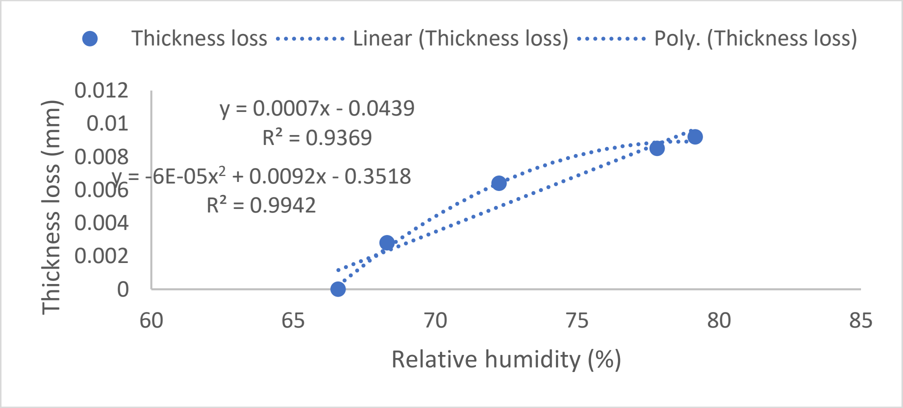

Figure 1: Relationship between deck plate thickness loss and relative humidity

Figure 1, shows calibrated models describing the relationship between the loss in deck plate thickness and relative humidity of the seawater environment. The quadratic equation, with an R^2 of 0.9942, provides a significantly superior fit compared to the linear equation, with R^2 value of 0.9369. This strongly suggests that the relationship between relative humidity and deck plate thickness loss is non-linear. This aligns with known corrosion mechanisms where a critical humidity threshold often exists, beyond which corrosion rates accelerate dramatically due to the formation of a continuous electrolyte film.

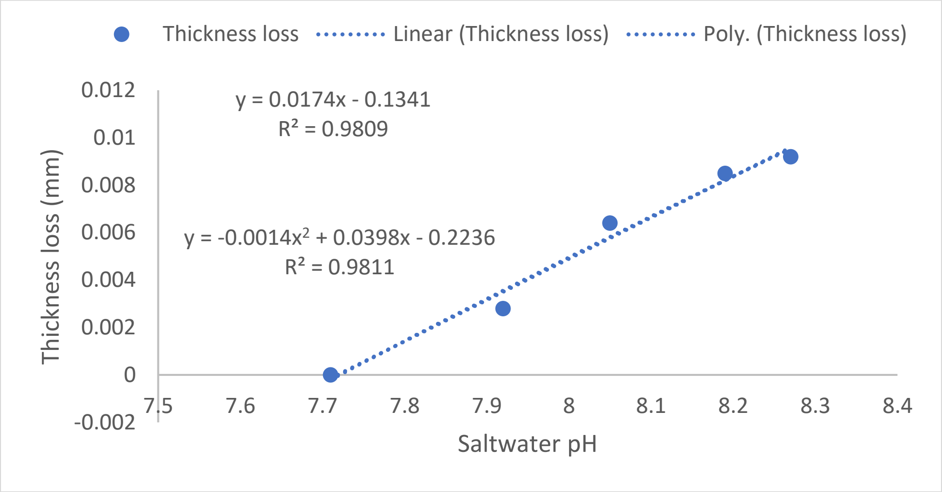

Figure 2: Relationship between deck plate thickness loss and saltwater pH

Figure 2 shows calibrated models for description of the relationship between the loss in deck plate thickness and pH of seawater. The regression equations are displayed with R^2 values. From the values, the quadratic equation has R^2 value of 0.9811, which is marginally higher than the linear equation with R^2 of 0.9809. While the difference is marginal, the quadratic equation has, technically, superior fit. This indicates a subtle non-linear relationship between the loss in deck plate thickness and pH of seawater. However, given the high R^2 for the linear model, a linear model can sufficiently be applied to predict the loss in thickness of the deck plate for a given pH of seawater.

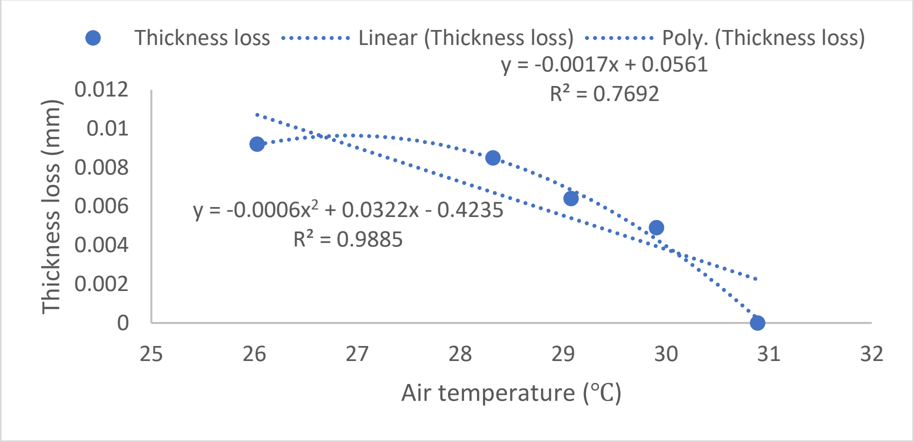

Figure 3: Relationship between deck plate thickness loss and air temperature

Figure 3 shows calibrated models describing the relationship between the deck plate thickness loss and air temperature within the seawater environment. The displayed R^2 values demonstrate that the quadratic equation substantially fitted the measured data better fit with an R^2 of 0.9885, as opposed to the linear equation with much lower R^2 value of 0.7692. This significant high R^2 indicates that the influence of air temperature on deck plate corrosion is markedly non-linear. Corrosion reactions are typically temperature-dependent, often following Arrhenius-type relationship, where reaction rates do not increase linearly with temperature.

Hence, the deck plate thickness loss can be estimated through the value of air temperature within the seawater environment, provided that all other corrosion indicator parameters remained relatively unchanged.

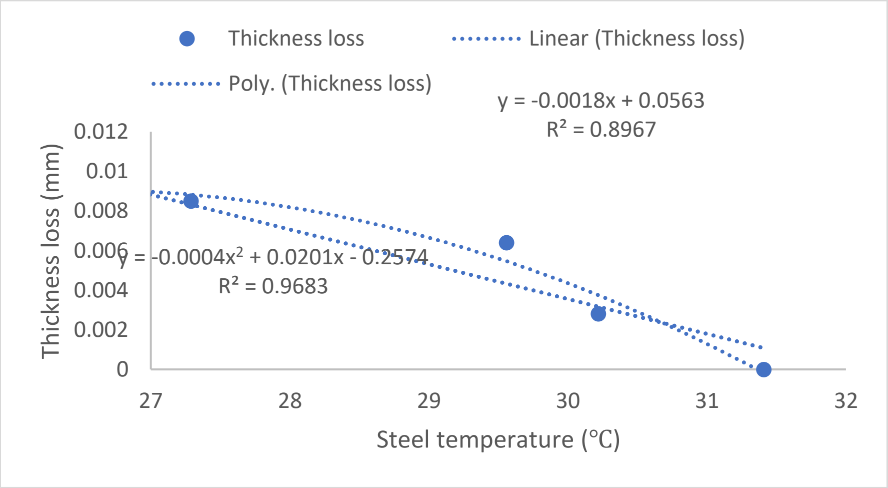

Figure 4: Relationship between deck plate thickness loss and steel temperature

Figure 4 shows calibrated models for description of the relationship between the deck plate thickness loss and steel temperature. The cumulative effect of temperature is critical for the degradation of deck plate in the offshore environment. It alters the electrochemical reaction kinetics and properties of the seawater as a corrosive media. Thus, the rise in temperature of the deck plate increases its surface hotness, thereby altering the mechanical and chemical properties of the coating material which protected the plate. This leads to loss of strength, toughness and corrosion resistance capacity of the deck plate.

Therefore, considering the impacts of temperature on corrosion of steel structures in marine environment, it is important to understand the relationship between the deck plate thickness loss and steel temperature. Nevertheless, the accurate interpretation of the relationship between the deck plate thickness loss and steel temperature depends on model used. The accuracy of both models was determined through the determination coefficient (R^2). As indicated in Figure 4.10, the displayed R^2 values demonstrate that quadratic equation provided better fit for interpretation of the relationship between the deck plate thickness loss and steel temperature (Ts). Thus, the R^2 value for quadratic equation is 0.9683, while for the linear equation it is 0.8967. This again shows that the non-linear relationship offers better explanation of losses in the deck plate thickness than the linear equation with respect to steel temperature. Therefore, the deck plate thickness loss can be estimated through the surface temperature of the deck plate.

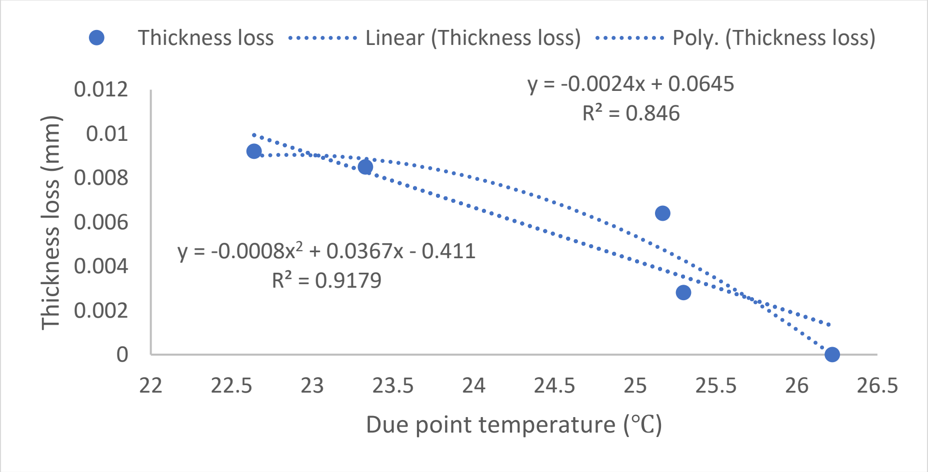

Figure 5: Relationship between deck plate thickness loss and dew temperature

The level of dew around corrosive media critically influences the rate of steel infrastructure degradation. Dew point temperature influences the duration of wetness and concentration of dissolved corrosive species on the surface of exposed infrastructures. Hence, establishing a mathematical relationship between dew point temperature and degradation of material can help to estimate the level of material deterioration. Figure 5 shows the models calibrated for description of the relationship between loss in deck plate thickness and dew temperature. For the calibrated equations, the R^2 value, as indicated in the figure, is 0.846 for the linear relationship and 0.9179 for quadratic relationship. This implies that the quadratic equation also explains the relationship between the deck plate thickness loss and dew point temperature better than the linear equation. This non-linear relationship between deck plate degradation and dew point temperature reflects the complex interplay of moisture accumulation and evaporation on the steel surface.

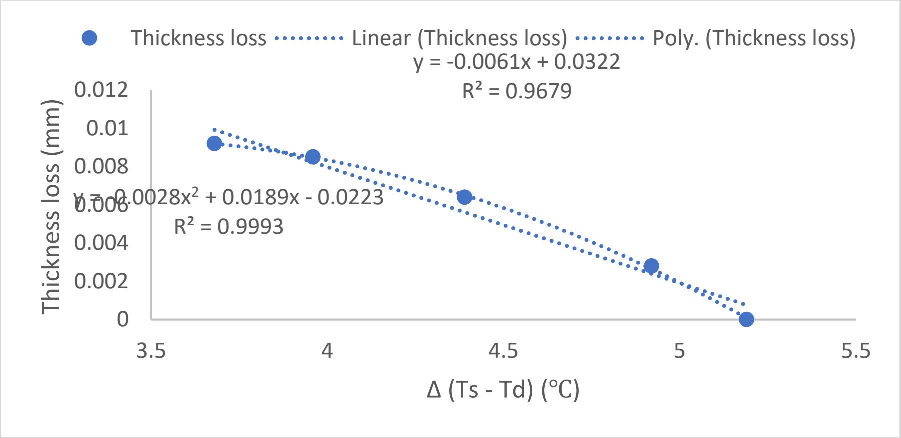

Figure 6: Relationship between deck plate thickness loss and Δ(Ts-Td)

Figure 6. shows the fitted equations for description of the relationship between loss in deck plate thickness and steel-dew point temperature difference (Δ [Ts - Td]). Δ(Ts - Td) has significant implication on corrosion of steel in corrosive media. As explained earlier, the formation and extent of condensation on materials surface depends on the temperature difference between the steel surface (Ts) and the dew point (Td). Thus, low Δ(Ts - Td) condition leads to sustained moisture deposits (condensation) on the surface of the material, and in saltwater environment, the moisture (electrolyte layer) formed is concentrated with chloride ions, which accelerates electrochemical reaction for corrosion to proceed.

As indicated in Figure 6, the quadratic equation has very high R^2 value of 0.9993, compared with R^2 value of 0.9679 obtained for the linear equation. This is significant, and it implies that the quadratic model fitted excellently with the measured data, and will perform better than the linear equation when used for prediction of deck plate thickness loss in terms of Δ(Ts - Td). Again, the relationship between deck plate thickness loss and Δ(Ts - Td) is non-linear. Therefore, small changes in the temperature difference can have disproportionately large impacts on corrosion of the deck plate. Therefore, effective control mechanism and management of deck plate in seawater environment is necessary.

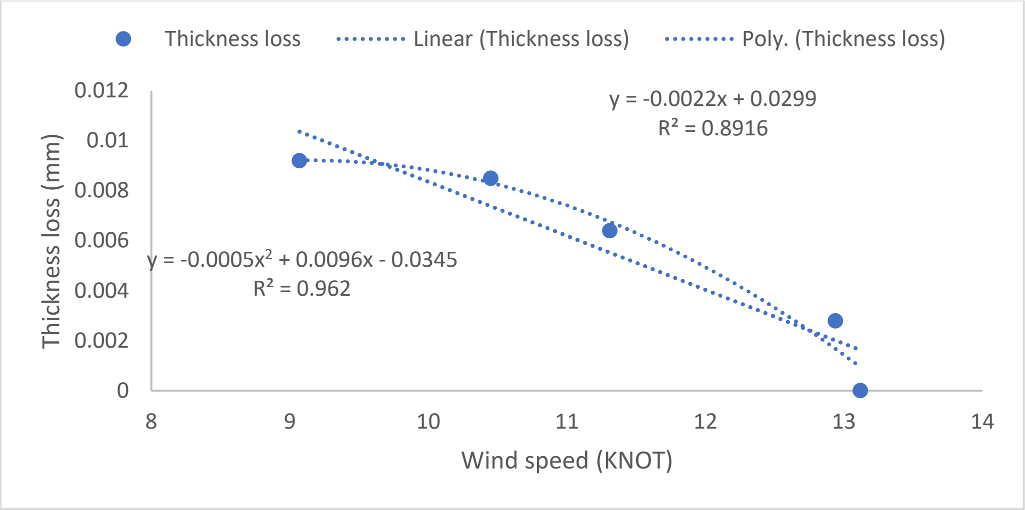

Figure 7: Relationship between deck plate thickness loss and wind speed

Figure 6 shows the fitted equations for description of the relationship between loss in deck plate thickness and wind speed (WS) of the seawater environment. Like the other parameters, the quadratic equation ($R^2 = 0.962$) provides a better fit than the linear equation ($R^2 = 0.8916$). This shows that the relationship between deck plate thickness loss and wind speed can best be described as non-linear. The non-linear relationship could be attributed to the complex influence of wind speed on various corrosion mechanisms, such as the facilitation of airborne pollutants deposition on infrastructures surface, dispersion oxygen and evaporation of moisture from the surface.

Generally, the quadratic equation consistently provides a better fit for interpreting the relationships between deck plate thickness loss and the various corrosion indicator parameters compared to the linear equation. Consequently, the underlying physical and chemical processes driving corrosion on deck plates are predominantly non-linear. This is expected, as seasonal variation (dry and wet seasons) changes over the years. This change also reflects on the variations in the complex and interacting environmental factors, which ultimately dictate the rate of deck plate corrosion. Further, the simple linear model also demonstrated capacity in estimating the deck plate thickness loss, but the obtained R^2 values indicate its accuracy is limited compared to the quadratic model, which is generally suited for prediction of plate thickness loss in terms of analysed corrosion indicator parameters. Hence, corrosion on steel infrastructures in sea or saltwater environment, such as offshore deck plate platform, can be monitored through the regression equations, especially quadratic model.

Table 4: Correlation Coefficient between Thickness Loss and Indicator Parameters63

	δ	*RH*	*pH*	*Ta*	*Ts*	*Td*	*Δ (Ts-Td)*	*WS*
δ	1							
RH	0.9680	1						
pH	0.9904	0.9659	1					
Ta	-0.9005	-0.9275	-0.9310	1				
Ts	-0.9469	-0.9870	-0.9672	0.9548	1			
Td	-0.9198	-0.9727	-0.9492	0.9457	0.9964	1		
Δ (Ts - Td)	-0.9838	-0.9923	-0.9817	0.9487	0.9799	0.9594	1	
WS	-0.9442	-0.9736	-0.9427	0.9691	0.9627	0.9416	0.9850	1

Table 4 presented further analysis carried out to validate the relationship between the deck plate thickness loss and the various environmental parameters associated to corrosion using Karl Pearson correlation coefficient. The results indicate strongly correlated relationship between the thickness loss of deck plates and the parameters. This is even striking as all the parameters have exceptional high correlation coefficients, exceeding 0.9. This signifies that these parameters are not merely related but are profoundly intertwined with the mechanisms governing corrosion and material degradation.

As shown in Table 4, relative humidity (RH) has a remarkably high positive correlation of 0.9680 with deck plate thickness loss (δ). This is affirmed that corrosion of the deck plate is significantly influenced by relative humidity. The positive correlation implies that increase in RH correspondingly increases the thickness loss. This agrees with the fact that humidity or moisture provides the medium for corrosive reactions to occur on the surface of the deck pate.

Conversely, the strong positive correlation between pH (0.9904) and thickness loss is rather unexpected, because corrosion of structural metals like steel, typically increase in acidic (low pH) condition. The observed positive correlation implies that higher pH values are associated with increased thickness loss. This could potentially indicate specific localised corrosion mechanisms or the influence of other factors. For instance, in some alkaline environments, certain forms of corrosion, or the formation of less protective corrosion products, might be promoted. Alternatively, this might be indicative of longer contact between the seawater and the deck plate, which could facilitate corrosion even at higher pH values, or due to biological activity that alters the surface chemistry.

The results also showed strong negative correlations between thickness loss and temperature parameters (ambient air temperature, Ta; steel surface temperature, Ts; and dew point temperature, Td), Δ (Ts - Td) and wind speed (WS). Conventionally, corrosion rate increases with rising temperature due to accelerated kinetic reaction. However, this analysis implies that the deck plate losses thickness even when air and steel surface temperatures are decreasing. This, in practice, negates the actual correlation between temperature and material degradation in the environment. The gradual loss in plate thickness despite decreasing Ta and Ts, points to the fact that the level of decrease in the environmental temperatures are not significant enough to translate the overall prevention of the deck plate corrosion. Further, the period of measurement (March to July) is mixed with dry and wet seasons. Approaching the wet season, the environment is more wet, and plays a dominant role on the corrosion process.

However, reduction of wind speed (WS), which has strong negative correlation of -0.9837 with thickness loss, decrease evaporation rate of moisture from the deck surface. This ensures prolonged time of deck plate wetness, thereby promoting corrosion, even at low temperatures. This is further strongly supported by the high negative correlation (-0.9691) between thickness loss and the temperature difference between the steel surface and dew point (Δ(Ts - Td)). Low Δ(Ts - Td) indicates high condensation, and consequently, a high likelihood of sustained wetness critical for corrosion.

The correlations results underscore the complex interplay of factors governing corrosion of infrastructure in marine environment. The overall relationships strongly highlight the critical role of moisture management on exposed deck plates. The results indicate that prolong surface wetness, which is indicated by high relative humidity and low temperature difference between the steel surface and dew point, are detrimental to steel infrastructures exposed to seawater. Therefore, it is crucial to develop effective corrosion prevention strategies, and maintenance practices that minimise the time of wetness on deck surfaces to extend the service life of marine structures.

4.0:Conclusion

In conclusion; the study indicates a progressive degradation of the deck plate thickness, with a transition to more aggressive corrosion mechanisms as time progresses. The deck plate thickness reduced to 0.0091 mm over 120 days, which represents 0.12% loss. The mechanism of the degradation, from visual analysis and inspection, revealed that the deck plate thickness loss was due to crevice and pitting corrosions. It also shows that relative humidity, seawater pH, temperature, and wind speed play crucial roles in the corrosion rate of the deck plate. At 120 days, the values of relative humidity, seawater pH and wind speed were 79.16%, 8.27 and 9.07 KNOT, respectively. The air, steel and dew point temperatures were 26.03 °C, 26.32 °C and 22.64 °C, while the difference between the steel and dew point temperatures was 3.68 °C. Overall, there is strong correlations between these environmental parameters and the deck plate thickness loss, emphasising the complex interplay of factors influencing material degradation in marine environments.

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