CORROSION OF OFFSHORE PLATFORMS OFF THE SOUTH-EAST COAST OF TRINIDAD

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ABSTRACT

Trinidad, the most southerly island of the Caribbean, is about 5,130 km² in area, situated just about 10 kilometres from the South American mainland, northeast of Venezuela, between 10 and 11 degrees north of the equator. The oil and gas industry is the mainstay of the economy of the unitary state of Trinidad and Tobago, derived mainly from offshore fields off the south-east coast of Trinidad. In such an environment, corrosion is a significant consideration in the maintenance of the platforms. Corrosion in offshore platforms is affected by several factors - relative humidity, temperature, sunlight, wind, water velocity, salinity, pH, oxygen concentration and marine organisms. The extent and effects of each of the above are outlined but the interplay of these factors results, in a complex way, in overall corrosion rates that are difficult to predict. The platforms are made basically of structural carbon steel. Corrosion rates were determined by exposing several coupons of the same type of structural carbon steel at various locations on one of the platforms. The results indicate that the marine environment off Trinidad's south-east coast is very corrosive, comparable to other very severe marine environments in other parts of the world.

1.0 INTRODUCTION

Oil and gas and related industries account for close to 30% of the GDP of Trinidad and Tobago, the energy sector being the country's largest foreign exchange earner. Natural gas is the source of energy and/or feed stock of several large plants involved in the manufacture of products such as methanol, fertilisers, gas liquids and iron and steel. Most of the oil and gas produced come from offshore fields off the south-east coast of Trinidad. Secondary recovery methods of production have become prevalent in the older oil fields so that the maintenance of the structural integrity of offshore platforms has assumed major significance, particularly for those that may have to continue to operate for several more years than originally anticipated, based on the initial design [1]. These structures are in the Atlantic Ocean off Trinidad in water depths ranging from about 25 - 67 metres and are all subjected to similar environmental conditions which can be equated to similar rates of corrosion.

A number of factors - relative humidity, temperature, sunlight, wind speed and direction, water velocity, salinity, pH, oxygen concentration, and marine organisms - affect the rate of corrosion of offshore platforms. It is important to understand the mechanisms of these parameters so that effective measures can be implemented in terms of corrosion control and monitoring techniques, schedules and surveys.

The extent of these factors and their effects on the rate of corrosion of one platform off the south-east coast of Trinidad have been studied. It is difficult to predict overall corrosion rates from the analysis of the different factors individually as their effects are not simply arithmetic. Since no suitable predictive model exists for the combined effects of the various factors which influence the corrosion rates, corrosion coupons of the same type of structural carbon steel, of which the platforms are constructed, were exposed at different positions on the platform as well as other areas in

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Trinidad. The rates of corrosion of these coupons were compared with rates of varying severity (rural, industrial, marine) in order to classify the environments. **Table 1** shows corrosion rates of structural carbon steel in various other locations [6].

LOCATION	TYPE OF ENVIRONMENT	CORROSION RATE (mm/yr)
Phoenix, Arizona	Rural Arid	0.01
State College, Pennsylvania	Rural	0.03
Pittsburgh, Pennsylvania	Industrial	0.04
Newark, New Jersey	Industrial	0.05
Kure Beach, North Carolina (240 m from ocean)	Moderate marine	0.15
Kure Beach, North Carolina (25 m from ocean)	Marine	0.53
Galeta Point Beach, Panama	Severe marine	0.68

Table 1: **Corrosion Rates of Structural Carbon Steel in Various Locations [6]**

2.0 CORROSION ZONES OF OFFSHORE PLATFORMS

Corrosion on offshore platforms may be divided into four zones - the mud zone, the submerged zone, the splash zone and the atmospheric zone [2]. (See **Figure 1**).

The mud zone is the portion of the structure lying below the ocean floor and consists essentially of the platform pilings. In this section, a shortage of oxygen tends to keep the corrosion rate at a low level, typically less than 0.03 mm/yr. [3] which is comparable to a benign rural area.

The submerged zone, as the name implies, is that part of the platform that is always covered by water. Corrosion in this zone is fairly uniform. However, in the area just below the mean low tide level, corrosion is greater due to the change in oxygen content at the interface which results in a differential aeration cell [2,3].

The splash zone is alternatively in and out of water due to the effects of the tides, wave action and wind. It is characterised by constant wetting by the waves and by splash and spray. The water film is thin and thus saturated with oxygen from the air resulting in maximum rates of diffusion. The mechanical action of the waves continually disrupts the layer of corrosion products which would otherwise afford some protection. It is also subjected to the mechanical action of boats, wires and other objects striking and destroying protective coatings. As a result, the splash zone is expected to experience the highest corrosion rate on the platform. The extent of the splash zone depends on the tidal range, the wind and the height of the waves. Off the south-east coast of Trinidad, the splash zone of platforms is typically about six metres [4].

The atmospheric zone extends upward from the splash zone and is exposed to sun, wind, spray and rain. The rate of corrosion in this zone is between that experienced by the submerged zone and the splash zone [2,3].

3.0 DETERMINATION OF CORROSION RATES

The corrosion rates of the different zones of the platform were determined by coupons placed in the upper three zones and exposed for six months, incorporating parts of both the dry and wet seasons. Coupons were also placed at different elevations on the beach in south-east Trinidad and in Central Trinidad in a rural environment (See **Table 2**). The preparation, installation and interpretation of data of the corrosion coupons were done according to the relevant standard recommended practice of the National Association of Corrosion Engineers (NACE) [5], as summarised in the next four paragraphs.

The coupons were initially cut from sheet into strips of 76.2 mm x 25.4 mm x 3.2 mm. They were cleaned in benzene, dried and lightly sandblasted to produce a uniform surface. Each one was punched with an identification number and weighed to ±0.1 mg. They were cleaned with benzene once more, dried and individually packaged in moisture-proof envelopes

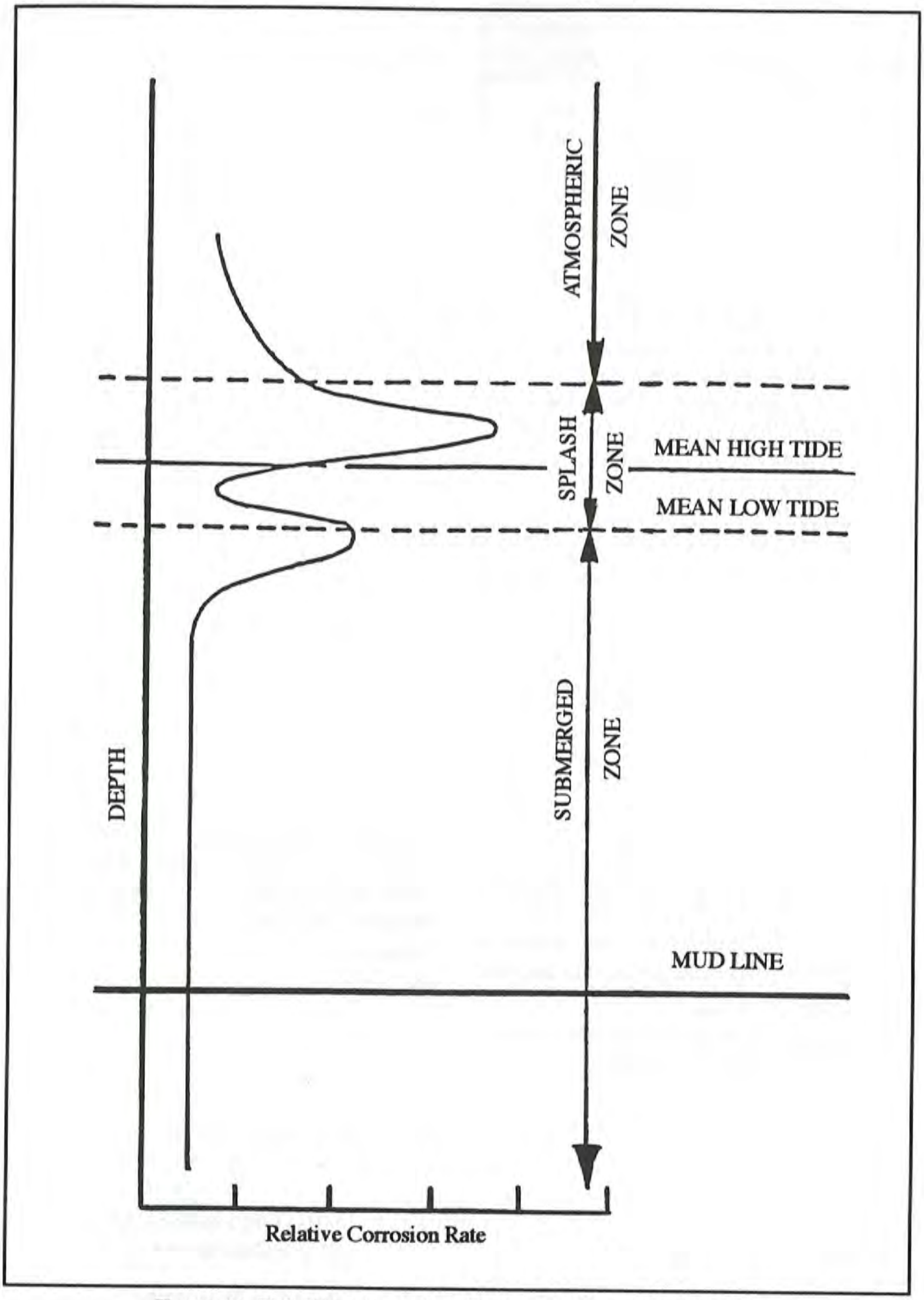

Figure 1: **Relative Corrosion Rates and Corrosion Zones for Steel Structure in Sea Water [2]**

LOCATION OF COUPON	CORROSION RATE (mm/yr)
Platform - Mean low tide region	0.41
Platform - Above mean high tide region	0.64
Platform - Upper splash zone	0.95
Platform - Atmospheric zone, 13m elevation	0.71
Platform - Atmospheric zone, 25m elevation	0.38
Beach - 10m elevation	0.69
Beach - 30m elevation	0.65
Whiteland - Shielded from elements	0.03
Whiteland - Exposed to elements	0.05

Table 2: **Corrosion Rates of Structural Steel Coupons placed on an Offshore Platform off the South-east Coast of Trinidad, on the South-east Coast Beach of Trinidad and in Rural Central Trinidad in Whiteland**

(with silica gel) which were stored in a closed box with silica gel also, taking care to handle them with clean rags (as opposed to bare hands) to avoid contamination with moisture, grease, etc.

The coupons were placed in the flat coupon holders and positioned on the platform structure such that the coupons were electrically isolated from the metal structure with the edges of the coupons in the direction of fluid flow.

After exposure, the coupons were cleaned in benzene, dried and immersed in 15% inhibited HCl for two minutes to remove all scale and oxide, then immersed in sodium bicarbonate for one minute to neutralise the acid. They were then rinsed in acetone, dried and weighed to ±0.1 mg.

The corrosion rate (in mm/yr) was calculated by dividing the weight loss of the coupon (after exposure) by the product of the density of the coupon, the total exposed surface of the coupon (including the edges) and the exposure time. For the structural steel used, the density was taken as 0.00786 g/mm^3.

As mentioned earlier, corrosion in the mud zone (below the ocean floor) is small as oxygen concentration is very low. The ocean floor subsurface off the south-east coast of Trinidad is not conducive to abnormal corrosion so that the typical rates of less than 0.03 mm/yr [3] are not expected to be exceeded. No coupons were placed in this area.

An inspection survey of the submerged zone of the platform revealed that it was covered with marine growth ranging in thickness from 50 mm from the ocean bed to a height of about 9 metres, generally increasing in thickness to as much as 150 mm towards the start of the splash zone. Corrosion was relatively uniform and there was no evidence of scouring of the (jacket) legs of the platform. A coupon was placed in the mean low tide region of the platform, where corrosion in this zone is maximum [2,3]. This region represents the borderline with the splash zone and the coupon here experienced a corrosion rate of 0.41 mm/yr which is in the typical range of such marine environments in the tropics [6].

Corrosion in the splash zone increases with increase in height from the mean low tide area. A coupon placed above the mean high tide region had a rate of 0.64 mm/yr and in the upper region of the splash zone, the rate was 0.95 mm/yr. This is considered a severe marine environment, normally considered to be > 0.70 mm/yr [6].

In contrast to the splash zone, corrosion rates in the atmospheric zone decrease with increasing height. At an elevation of 13 metres, the rate was 0.71 mm/yr, falling to almost half (0.38 mm/yr) as the distance is about doubled to an elevation of 25 metres.

At the beach on the south-east coast of Trinidad, at an elevation of 10 metres, the corrosion rate was 0.69 mm/yr, decreasing as the height increases, being 0.65 mm/yr 3 metres higher. This is typical of rates found in the tropical and sub-tropical beaches in the Atlantic [6]. The lower rate for the rural area of Whiteland in Trinidad (0.03 mm/yr) is for a coupon that was shielded from direct contact with the elements and is comparable to rural eastern United States [6]. The coupon in Whiteland that was exposed to the elements experienced a corrosion rate (0.05 mm/yr) closer to rates in industrial USA [6]. This is most likely due to the tropical climatic conditions in Trinidad with relatively high temperature and humidity.

4.0 FACTORS AFFECTING CORROSION RATES

4.1 Relative Humidity

Atmospheric corrosion rates increase with increase in relative humidity. A very steep rise occurs for relative humidities of over 60% in iron [7]. A wet marine atmosphere, where condensed moisture is visible to the naked eye (corresponding to 100% relative humidity), is a very aggressive corrosive environment for steel. Under such conditions, the corrosion process is analogous to that of continuous sea-water immersion except that the thin wet electrolytic film has a marked effect on the character of the corrosion pattern, the corrosion products, and the ease with which oxygen is transferred to the metal surface, resulting in accelerated corrosion [3].

In a moist marine atmosphere (at relative humidities of less than 100%), such as those off the south-east coast of Trinidad where relative humidities range from 80 - 85% [8], the electrolytic films on the metal surfaces are invisible to the naked eye and normally very thin. Under these circumstances, dust, salt deposits and corrosion products enhance the corrosion process by entrapping moisture and allowing the electrolytic films to thicken and become continuous [3]. The level of corrosion resulting from such a condition may be as extensive as that of the wet marine atmosphere.

4.2 Air Temperature

The corrosion rate of iron rises steadily with increase in temperature from 20 - 40°C. Air temperature affects relative humidity, dew point, and the time of wetness. For atmospheric corrosion, the moisture as determined by the time of wetness is probably the most important variable affected by temperature [7]. In the offshore environment off Trinidad's south-east coast temperature varies between 20 and 35°C. The temperature during the day is usually in the low to middle thirties (°C) which is in the high range for atmospheric corrosion of structural steel in high humidity.

4.3 Sunlight

As Trinidad is near to the equator (10 - 11° N latitude) the sun is almost directly overhead at midday. In the environment of high relative humidity, high evaporation rates and average diurnal changes in temperature of about 10°C, the alternative drying and wetting of metal surfaces in the salt-laden atmosphere cause localised acceleration of corrosion because of the disruption of natural protective films on the steel [7].

4.4 Wind

The direction and velocity of the wind affect the rate of accumulation of particles on metal surfaces. It has a pronounced effect on the corrosion rates experienced off the south-east coast of Trinidad. The east coast is directly exposed to the strong prevailing north-east trade winds blowing over a large uninhibited mass of water (the Atlantic Ocean).

Wind is the major cause of wave action which results in intermittent wetting in the splash zone. Wind also whips up the water surface and captures salt spray from breaking waves. The salt-laden moisture in the air evaporates and the remaining salt dust is deposited on the metal surfaces. These salt particles accelerate the corrosion of the steel surfaces to which they adhere because they attract and retain moisture (being hygroscopic) and form aggressive local cells [7].

4.5 Salinity

The most commonly measured property of sea-water is its salinity. The water in the open ocean varies somewhat in its salinity, ranging from about 3.2% to 3.6% in the colder regions and greater than that in the tropics [7]. An analysis of the sea-water in the region of the platform shows a salinity of about 3.9% [9]. The major components responsible for its salinity are given in **Table 3**. It should be noted that, in general, the open ocean salinity variations with horizontal location and depth are quite small [7].

The main effects of salinity on corrosion result from its influence on the conductivity of the water and from the influence of chloride ions on the breakdown of protective passive films formed by corrosion

IONS	g/kg OF SEA-WATER
Chloride, Cl	22.117
Sodium, Na	12.261
Sulfate, SO_4	2.700
Magnesium, Mg	1.560
Calcium, Ca	0.444
Bicarbonate, HCO_3	0.217

Table 3: **Constituents of Water in the Ocean off the East Coast of Trinidad contributing to Salinity [9]**

products. Natural waters vary considerably in their resistivity. Pure water has a resistivity of 20,000,000 ohm-cm and rain water of the order of 20,000 ohm-cm. Sea-water with a presence of some 40,000 ppm of dissolved salts has a resistivty of about 15 ohm-cm in the tropics, rising to about 50 ohm-cm in the Arctic regions [7].

Of the various ions in sea-water resulting from dissolved salts, the chloride ion is the most significant because of its large concentration. The higher the salinity of the water, the more readily chloride ions succeed in penetrating the passive film and initiating pitting and crevice corrosion at localised sites on the metal surface.

4.6 Oxygen Concentration

Oxygen is the principal corroding agent of steel in sea-water. The rate and concentration at which oxygen arrives at the metal surface determines, to a large measure, the rate of corrosion due to its ability to remove the sheath of hydrogen gas deposited on the cathode surface [7, 10].

Variations in oxygen concentration on the surface of the steel, as a function of water depth, accelerates the corrosion reaction by formation of differential aeration cells along the length of the leg of the platform, analogous to a galvanic cell. Areas of low concentrations of oxygen are anodic to areas of higher concentration. The increased corrosion rate in the submerged zone just below mean low water level is attributed to the action of such a differential aeration cell [7].

Measured oxygen concentration levels of sea-water in the vicinity of the platforms off Trinidad's south-east coast are about 6 ppm just below mean low water level and about 4 ppm at a water depth of about 30 metres [9]. Any mechanism that enhances the arrival of oxygen to the bare steel surface immersed in sea-water, such as wave action, water velocity, abrasion by mud or sand, or increasing temperature, will generally increase the corrosion rate, provided the oxygen concentration remains the same and there are no barriers at the metal interface [4, 7]. These mechanisms, while nothing as severe as in the North Sea for example, are still much higher for the ocean off Trinidad's south-east coast than those normally encountered in other areas of the world where platforms are located, and no doubt contribute to the high corrosion rates experienced.

4.7 pH Value

Within the range of about pH 4 to pH 10, the corrosion rate is not too much dependent on the pH value. As alkalinity is increased above pH 9.5, iron tends to become passive and forms protective films which retard diffusion of oxygen to the surface. Below pH 4, alkaline protective films are dissolved and the acid acts directly on the metal, accompanied by evolution of hydrogen. The pH of the sea-water off the south-east coast of Trinidad ranges from about 7.4 to 8.2 [9] and as a result corrosion rate is not influenced.

4.8 Water Temperature

Sea-water temperature is a complex variable in corrosion reactions. When all other factors are held constant, an increase in temperature increases the corrosivity of sea-water. For instance, if the dissolved oxygen concentration is held constant, the corrosion rate of low carbon steel in sea-water will approximately double for each 30°C increase in temperature [7].

The increase in corrosion rate in the warmer surface waters of the tropics is usually offset by an increase in marine fouling rate, which provides a protective covering over the metal surface. There is a decrease in oxygen solubility at higher temperatures which also exerts a retarding influence on the corrosion rate. Thus, contrary to expectations, corrosion rates in tropical sea-waters in the submerged zone of offshore platforms have not been found to differ significantly from those measured in the cooler northern latitudes [3].

4.9 Water Velocity

Increasing velocity of sea-water results in an increase in the rate of corrosion of steel members. The increased rate of corrosion is attributed to the increased availability and rate of diffusion of oxygen through the stagnant hydrodynamic sublayer (diffusion sublayer) of liquid on the surface of the metal.

As velocities increase, the diffusion sublayer thickness decreases with the resulting increase in oxygen transport to the metal surface. The rate of corrosion usually reaches a maximum value with increasing velocity, as film formation on the metal surface, rather than hydrodynamic considerations, begins to control the amount of oxygen reaching the metal surface [10]. The effect on velocity in increasing corrosion only applies when the steel is in contact with the moving sea-water. Accumulation of fouling organisms will reduce the velocity at the metal-sea-water interface so that corrosion will not be affected much by variations in the flow rate outside the attached organisms. This is an important factor for Trinidad and Tobago's offshore platforms. These platform legs have a considerable amount of marine growth and hence water velocities, which are normally under 5 m/sec [4], will have reduced influence on corrosion rates in the submerged zone.

4.10 Marine Organisms

Organic matter in the sea has a marked effect on corrosion. The fouling community consists of a vast variety of marine plants and animals which attach themselves to marine structures. These organisms, such as barnacles, grasses and worms, to name a few common types, generally accelerate the corrosion rate in localised areas because of differential environmental conditions caused by their biological processes. Many bacterial slimes increase fouling rates by providing food for barnacles, and by darkening and roughening surfaces encourage fouling attachment. In some cases, chlorophyll-containing plants such as plankton enrich the oxygen content in surface layers of the water, thus facilitating corrosion. Dense, continuous marine growths can sometimes stifle general corrosion by impeding the diffusion of oxygen to the metal surface [7]. The legs of the platform off Trinidad's south-east coast are covered with this latter type of growth ranging from 50 to 150 mm thick. Hence the rate of corrosion is likely to be reduced as a result.

5.0 CONCLUSIONS

The major findings and conclusions resulting from this study are as follows:

- Corrosion is found to be most extensive in the upper splash zone area and least in the mud zone area where the rate in the latter zone does not differ essentially from offshore platforms in varying marine environments.

- The marine environment off Trinidad's south-east coast can be classified as severe marine. Corrosion rates measured for the different zones for the offshore structures reveal that this environment compares with that in other parts of the world where corrosion is extensive.

- The high degree of corrosion experienced on the offshore structures in the tropical waters off the south-east coast of Trinidad can be attributed mainly to the high relative humidity, warm temperatures, high salinity, high water velocities, and direction and velocity of the prevailing north-east trade winds. However, marine growth in the submerged zone tends to decreasse corrosion rates.

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