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The determination of the rate of corrosion of carbon steel in different aqueous environment

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ABSTRACT

Corrosion is one of the major issues we face today, hence, this research work was designed to determine the rate of corrosion of carbon steel in different aqueous environments. The correction is induced by the exposure of the carbon steel to different location or environment such as sea water environment, fresh water and alkaline environment, which contains oxygen and water, since these are one of the major agents of corrosion. This is based on the experiment which involves the immersion of carbon steel into these exposed locations and effect of different corrosion was considered. The exposure time varies between 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70 (days), respectively. From this research, the behavior of corrosion of carbon steel have been examined and investigated based on the exposed location or environment and results revealed that the environmental conditions and corrosion agents has variable impact on the carbon steel.

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Capsule Summary: The rate of corrosion of carbon steel in different aqueous environments like sea water environment, fresh water and alkaline environment, which was studies up to 70 days and the environmental conditions and correction agents showed variable correction effect on the carbon steel.

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INTRODUCTION

If corrosion is not taken into proper consideration it could lead to fatal destruction of life and properties. Corrosion can begin from the design stage to the operational stage; that is why it is defined as the deterioration of metal as a result of reaction with its environment (Ailor, 1971). Corrosion has constantly become a major problem in areas of engineering (Petroleum exploration, processing, production, transportation, agriculture and design engineering) etc. It has attained a global concern and is felt in all human endeavor. The destruction and financial effect, which in some countries runs into billions of dollars annually cannot be overemphasized. For example, it was recorded that in 1994, 140 million ton of steel were produced in United States at a cost of approximately $400 per ton. This gives a monetary loss by corrosion of about 1.7 billion dollar (Boyd and Fink, 1978). The reason why designers and operators are often surprise by the occurrence of corrosion is because most operators take little trace of corrosion not seriously because they believe it will take months before it will deteriorate. However, improved corrosion monitoring and measuring instrument has shown that corrosion rate may vary by hour, day and week (Champion, 1964). Seawater is one of the most corrosive and most abundant naturally occurring electrolyte.

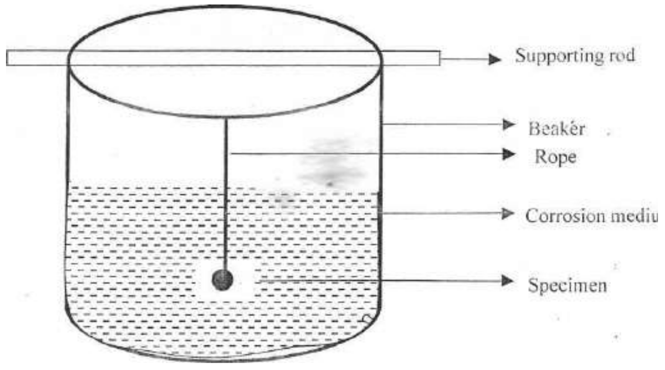

Fig. 1: Corrosion medium and set-up

The corrosivity of the seawater is reflected by the fact that carbon steel are attacked by this liquid or is surrounding environment by (Anonymous, 2007). The determination of the rate of carbon steel in three different aqueous environment such as sea water, fresh water sand alkaline is based on immersing carbon steel into these various aqueous environments and the effect of the medium on carbon steel (Laque, 1975).

The aim of determining the rate of corrosion of carbon steel is for safety and economic purposes because pipelines, vessels and other equipment which constitute an oil field production system are handling fluid that is flammable which may be at high pressure, anti-corrosion measure are necessary. If a well, pipeline or building were to fail due to corrosion, not only would the cost of repair be high but the value of product lost to the construction company will be many times higher (Fortana, 1987).

The question is not whether carbon steel will corrode but how fast within a particular medium carbon steel will corrode. The rate of corrosion is the most important parameter and will determine the life of a given carbon steel. The objective is to: Assess the efficiency of different corrosion protective method, Select the most effective corrosion protective method and develop recommendations to arrange corrosion protection for casing (Reinhart, F. M and Jenkins, 1972; Timber, 1984).

The study of corrosion thus resolves itself into the finding of the factors influencing the scale and distribution of the attack on carbon steel. The most important factor being the physical and chemical properties of the initial corrosion product; it distributions and it ability to withstand chemical/mechanical damage when formed in the metal/environment interface (Fortana, 1987). The effect of corrosion on carbon steel is greatly influenced by the environment they find themselves. Some constituent can aggregate attack on some metals like carbon steel while protecting others and some constituent can accelerate attack on metal under some circumstance and retard it under others (Oildfield and Todd, 1979). The reason of this project is to help choose specific material appropriate to the anticipated environmental conditions and adjusting controllable environment that favors the best performance of the chosen material.

MATERIAL AND METHODS

Experimental procedure

Carbon steel were cut into rectangular shape using ruler to know the length and width of the carbon steel, venier caliper was used to measure the thickness of the carbon steel. Three carbon steel were provided, three for the coated and three for the uncoated. The coated sample was to act as the control of the experiment. A smoothing file were used to dress the edge of the carbon steel to remove rough filing. A hole was drilled in the middle of the carbon steel and ropes were inserted in the middle for easy immersion and removal. Initial weight of the carbon steel was measured using the analytical balance and recorded.

A beaker containing seawater, freshwater and alkaline were provided, each carbon steel was suspended in the corrosion medium through a supporting rod and rope, each beaker has it label to distinguish the beakers. This is followed by putting the carbon steel into the beaker. The carbon steel was kept for a period of 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70. After the expiration of the exposed time, the carbon steel was removed from the beaker.

Cleaning procedure

There are several ways of cleaning the specimen after removal from the exposed location. One common cleaning procedure consists of holding the specimen under a stream of tap water and vigorously scrubbing the surface of the carbon steel with rubber stopper. The rubber stopper cleaning methods has been found satisfactory for most corrosion test in practical application involving aqueous solution and also for many other test. Cleaning method may be classified as: Mechanical, such as scraping, brushing, scrubbing with abrasive, sand blasting and rubber stopper, chemical, such as the use of chemicals and solvent and electrolytic which involve making the specimen 'the cathode under an impressed current in a variety of chemical reagent with or without inhibitor added.

The method used here in cleaning the specimen is mechanical method, the specimen was removed from the exposed location and washed with distilled water to remove sand and other impurities. An iron brush was used to scrub the oxide film formed on the carbon steel and while using the brush care was taken to ensure no further loss of metal apart from the film formed on the carbon steel. After the removal of the specimen from the exposed locations and cleaning process is carried out, the specimen is dried and weighed on an analytical balance. The weight loss of each exposed time is recorded, the recorded weight loss was used in calculating the corrosion rate.

RESULTS AND DISCUSSION

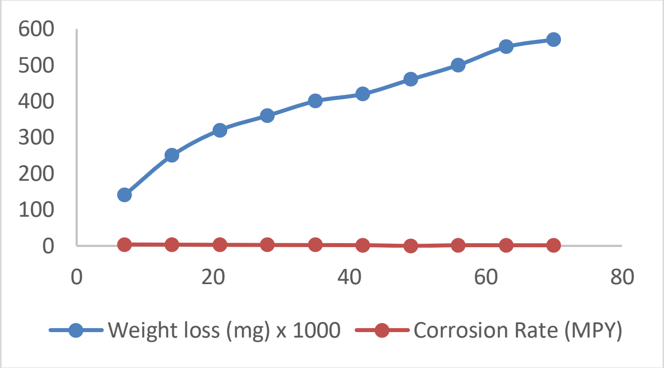

Fig. 2: Plot of relationship between weight loss and corrosion rate in a sea water environment

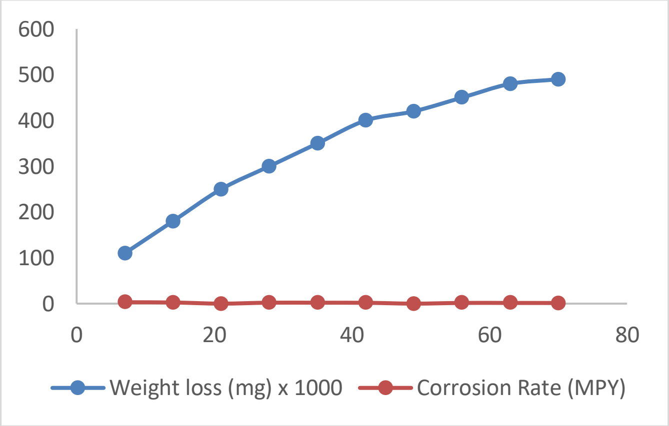

Fig. 3: Plot of relationship between weight loss and corrosion rate in a fresh water environment

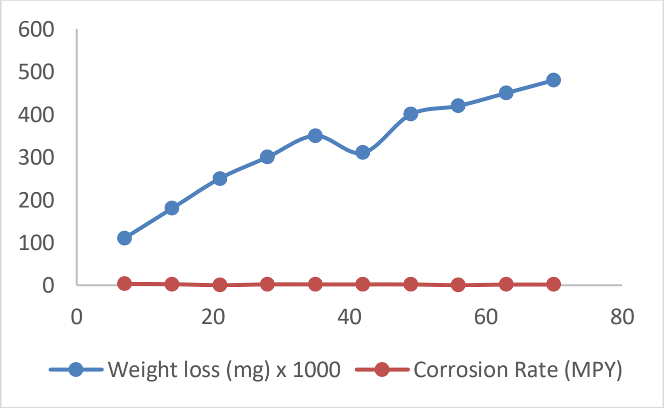

Fig. 4: Plot of relationship between weight loss and co
alkaline environment

The result of the corrosion rate are used in plotting the profile shown in the following sections.

Corrosion rate

The formula for the rate of corrosion is presented in Eq. 1.

$$CR = \frac{\Delta w}{D \times A \times T} \qquad (1)$$

Where, CR = corrosion rate, Δw = weight loss (mg), D = density of specimen (g/cm^3), A = area of specimen (sq.in) T = exposure time (hr), Density of carbon steel = 7.86 g/cm, Area of steel = 75 mm x 50 mm = 3750 mm (Eq. 2).

$$\frac{3750mm}{100} = 375\ cm \qquad (2)$$

Where, 1 centimeter x 0.3937 = 1 inch, 37.5 cm to inch and 37.5 cm x 0.3937 = 14.7 inch

Corrosion rate in seawater

7 days

Δw = 0.14 g x 1000 = 140 mg
ℓ = 7.86 g/cm^3
ℓt = 7 x 24 = 168 hrs
A = 14.7sq.in
CR = $\frac{(140 \times 534)MPY}{7.86 \times 14.7 \times 168}$ = 3.8514 MPY

14 days

Δw = 0.25 g x 1000 = 250 mg
ℓ = 7.86 g/cm^3
ℓt = 14 x 24 = 336 hrs
A = 14.7 sq. In
CR = $\frac{(250 \times 534)MPY}{7.86 \times 14.7 \times 336}$ = 3.4387 MPY

21 days

Δw = 320 mg = 0.32 x 1000 = 320 mg
ℓ = 7.86 g/cm^3
ℓt = 21 x 24 = 504 hrs
A = 14.7 sq. In
CR = $\frac{(250 \times 534)MPY}{7.86 \times 14.7 \times 504} = \frac{170880}{58{,}233.168} = 2.9344\ MPY$

28 days

Δw = 360 mg = 0.36g x 1000
ℓ = 7.86 g/cm^3
ℓt = 28 x 24 = 672 hrs
A = 14.7 sq. In
CR = $\frac{(360 \times 534)MPY}{7.86 \times 14.7 \times 672} = \frac{192240}{77{,}644.224} = 2.4759\ MPY$

35 days

Δw = 400 mg = 0.40 g x 1000
ℓ =7.86 g/cm^3
ℓt = 35 x 24 = 840 hrs
A = 14.7 sq. In
CR = $\frac{(400 \times 534)MPY}{7.86 \times 14.7 \times 840} = \frac{213600}{97055.28} = 2.2008$

Table 1: Composition of seawater

Element	At. weight	PPM
Hydrogen	1.000797	110,000
Oxygen	15.9994	833,000
Sodium	22.9898	10.300
Chlorine	35.453	19, 400
Sulphur	32.312	904
Potassium	39.102	392
Calcium	10.08	411
Bromine	79.909	67.3
Carbon	12.011	28.0
Nitrogen ion	14.007	15.5
Magnese	54.938	0.0004
Magnesium	24.312	1, 290

Table 2: Composition of fresh water

Composite	Unit	Value
Chloride	Mg/L	23
Sulphate	Mg/I	4
Calcium	Mg/I .	2
Maganese	Mg/I	0.10
Copper (cu^{2+})	Mg/I	0.00
Iron (Fe2+)	Mg/I	0.10
Zinc (2n2+)	Mg/I	6.5

42 days

Δw = 420 mg = 0.40 g x 1000
ℓ =7.86 g/cm^3
ℓt = 42 x 24 = 1008 hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(420 \times 534)MPY}{7.86 \times 14.7 \times 1008} = \frac{224280}{116{,}466.336}$$

49 days

Δw = 0.46 mg = 0.96 x 1000 = 460 mg
ℓ =7.86 g/cm^3
t = 49 x 24 = 1176 hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(460 \times 534)MPY}{7.86 \times 14.7 \times 1176} = \frac{245640}{135{,}877.392} = 1.8078\ MPY$$

56 days

Δw = 500 mg = 0.50 g x 500 mg
ℓ= 7.86 g/cm^3
t = 56 x 24 = 1344 hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(500\text{x } 534)MPY}{7.86 \times 14.7 \times 1344} = \frac{267000}{155{,}286.44} = 1.7193MPY$$

63 days

Δw = 550 mg = 0.55 g x 1000 = 550 mg
ℓ = 7.86 g/cm^3
t = 63 x 24 = 1512 hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(550 \times 534)MPY}{7.86 \times 14.7 \times 1512} = \frac{267000}{155{,}286.44} = 1.6811MPY$$

70 days

Δw = 570 mg = 0.57 g x 1000
ℓ = 7.86 g/cm^3
t = 70 x 24 = 1680hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(570 \times 534)MPY}{7.86 \times 14.7 \times 1680} = \frac{309380}{194110.56} = 1.5680MPY$$

Corrosion rate in freshwater

7 days

Δw = 120 mg = 0.12 g x 1000 = 120 mg
ℓ = 7.86 g/cm^3
t = 7 x 24 = 168hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(120 \times 534)MPY}{7.86 \times 14.7 \times 168} = \frac{64080}{194110.56} = 3.3012MPY$$

14 days

Δw = 200 mg = 0.20 g x 1000 = 200 mg
ℓ =7.86 g/cm^3
t = 14 x 24 = 336 hrs
A = 14.7 sq. In
CR = $\frac{(200 \times 534)MPY}{7.86 \times 14.7 \times 336} = \frac{106800}{38{,}822.112} = 2.7510MPY$

21 days

Δw = 230 mg = 0.23 g x 1000 = 230 mg
ℓ = 7.86 g/cm^3
t = 21 x 24 = 504 hrs
A = 14.7 sq. In
CR = $\frac{(230 \times 534)MPY}{7.86 \times 14.7 \times 504} = \frac{122820}{58{,}233.168} = 2.1091MPY$

28 days

Δw = 250 mg = 0.25 g x 1000 = 230 mg
ℓ =7.86 g/cm^3
t = 28 x 24 = 672 hrs
A = 14.7 sq. In
CR = $\frac{(250 \times 534)MPY}{7.86 \times 14.7 \times 672} = \frac{133500}{77644.224} = 1.7193MPY$

35 days

Δw = 300 mg = 0.30 g x 1000 = 300 mg
ℓ = 7.86 g/cm^3
t = 35 x 24 = 840 hrs
A = 14.7 sq. In
CR = $\frac{(420 \times 534)MPY}{7.86 \times 14.7 \times 672} = \frac{224280}{155.288.440} = 1.442MPY$

42 days

Δw = 350 mg = 0.35 g x 1000 = 350 mg
ℓ = 7.86 g/cm^3
t = 42 x 24 = 1008 hrs
A = 14.7 sq. In
CR $= \frac{(460 \times 534)MPY}{7.86 \times 14.7 \times 1512hr} = \frac{160200}{97055.28} = 1.6506MPY$

49 days

Δw = 400 mg = 0.40 g x 1000 = 400 mg
ℓ = 7.86 g/cm^3
t = 49 x 24 = 1176 hrs
A = 14.7 sq. In
CR = $\frac{(400 \times 534)MPY}{7.86 \times 14.7 \times 1176} = \frac{213600}{135.877.392} = 1.5720MPY$

56 days

Δw = 420 mg = 0.42 g x 1000 = 420 mg
ℓ = 7.86 g/cm^3
t = 56 x 24 = 1344 hrs
A = 14.7 sq. In
CR = $\frac{(420 \times 534)MPY}{7.86 \times 14.7 \times 1344} = \frac{224280}{155.288.440} = 1.4442MPY$

63 days

Δw = 460 mg = 0.46 g x 1000 = 460 mg
ℓ = 7.86 g/cm^3
t = 63 x 24 = 1512 hrs
A = 14.7 sq. In
CR = $\frac{(420 \times 534)MPY}{7.86 \times 14.7 \times 1344} = \frac{224280}{155.288.440} = 1.4442MPY$

70 days

Δw = 500 mg = 0.50 g x 1000 = 500 mg
ℓ = 7.86 g/cm^3
t = 70x 24 = 1680 hrs
A = 14.7 sq. In
CR = $\frac{(420 \times 534)MPY}{7.86 \times 14.7 \times 1344} = \frac{245640}{174699.504} = 1.4060MPY$

Corrosion rate in alkaline condition

7 days

Δw = 110 mg = 0.10 g x 1000 = 110 mg
ℓ = 7.86 g/cm^3
t = 7 x 24 = 168 hrs
A = 14.7 sq. In
CR = $\frac{(110 \times 534)MPY}{7.86 \times 14.7 \times 1176} = \frac{58740}{19411.056} = 3.0261MPY$

14 days

Δw = 2580 mg = 0.25 g x 1000 = 250 mg
ℓ =*7.86* g/cm^3
t = 21 x 24 = 504 hrs
A = 14.7 sq. In
CR =$\frac{(250 \times 534)MPY}{7.86 \times 14.7 \times 336} = \frac{160200}{77644.224} = 2.0632MPY$

28 days

Δw = 300 mg = 0.30 g x 1000 = 300 mg
ℓ = 7.86 g/cm^3
t = 28 x 24 = 672 hrs
A = 14.7 sq. In
CR =$\frac{(300 \times 534)MPY}{7.86 \times 14.7 \times 672} = \frac{160200}{77644.224} = 2.0632MPY$

35 days

Δw = 350 mg = 0.35 g x 1000 = 350 mg
ℓ = 7.86 g/cm^3

Table 3: pH of the environment

Environment	pH
Seawater	7.2
Freshwater	7
Alkaline	10

Table 4: Corrosion rate in seawater

Sample	Initial weight (g)	Final weight (g)	Weight loss (mg) x 1000	Corrosion Rate (MPY)
7	50.50	50.36	140	3.8514
14	46.25	48.00	250	3.4387
21	48.32	48.00	320	2.9344
28	47.86	47.50	360	2.4759
35	47.90	47.50	400	2.2008
42	46.42	46.00	420	1.9257
49	46.46	46.00	460	1.8078.
56	45.50	45.00	500	1.7193
63	45.65	45.10	550	1.6811
70	44.67	44.10	570	1.5680

Table 5: Corrosion rate in fresh water

Sample	Initial weight (g)	Final weight (g)	Weight loss (mg) x 1000	Corrosion Rate (MPY)
7	51.11	51.00	110	3.0261
14	50.18	50.00	180	2.4759
21	49.90	49.65	250	2.2925-
28	49.60	49.30	300	2.0632
35	49.50	49.15	350	1.9257
42	48.60	48.20	400	1.8340
49	47.82	47.40	420	1.6506.
56	46.90	46.45	450	1.5474
63	46.80	46.32	480	1.4672
70	46.82	46.31	490	1.3479

Table 6: Corrosion rate in alkaline solution

Sample	Initial weight (g)	Final weight (g)	Weight loss (mg) x 1000	Corrosion Rate (MPY)
7	51.11	51.00	110	3.0261
14	50.18	50.00	180	2.4759
21	49.90	49.65	250	2.2925-
28	49.60	49.30	300	2.0632
35	49.50	49.15	350	1.9257
42	48.60	48.20	400	1.8340
49	47.82	47.40	420	1.6506.
56	46.90	46.45	450	1.5474
63	46.80	46.32	480	1.4672
70	46.82	46.31	490	1.3479

t = 35 x 24 = 840 hrs
A = 14.7 sq. In
CR = $\frac{(350 \times 534)MPY}{7.86 \times 14.7 \times 840} = \frac{186.900}{97055.28} = 1.9257MPY$

42 days

Δw = 420 mg = 0.42 g x 1000 = 420 mg
ℓ = 7.86 g/cm^3
t = 49x24 = 1176 hrs
A = 14.7 sq. In
CR = =$\frac{(420 \times 534)MPY}{7.86 \times 14.7 \times 1176} = \frac{22480}{135877.392} = 1.6506\ MPY$

56 days

Δw = 450 mg
ℓ = 7.86 g/cm^3
t = 564 x 24 = 1344 hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(450 \times 534)MPY}{7.86 \times 14.7 \times 1344} = \frac{240300}{155{,}288.448} = 1.5474\,MPY$$

63 days

Δw = 480mg
ℓ = 7.86 g/cm^3
t = 63 x 24 = 1512hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(470 \times 534)MPY}{7.86 \times 14.7 \times 1512} = \frac{256320}{174{,}699.504} = 1.4672\,MPY$$

70 days

Δw = 490 mg
ℓ = 7.86 g/cm^3
t = 70 x 24 = 1680 hrs
A = 14.7 sq. In

$$\text{CR} = \frac{(490 \times 534)MPY}{7.86 \times 14.7 \times 1680336} = \frac{261660}{194110.56} = 1.3479\,MPY$$

Table 4-6 shows that corrosion rate of carbon steel used at different exposure site and under different exposure time. The result shows that carbon steel corrosion in seawater has the maximum, corrosions rate whilst eh caron steel corrosion in alkaline shows that lowest corrosion rate. Figure 2 through 4 shows the relationship between weight loss and corrosions rate in the three aqueous environments namely, seawater, freshwater and alkaline solution respectively. In all the three figures the corrosion rate decreases with increasing weight loss. The relationship between the exposure time (days) and corrosion rate in the three exposures location in all the three figures the corrosion rare decrease with increasing exposure time (days). The reason is that as the exposure time (days) increases, the carbon steel that is immersed in the exposure sites get reduced because it has been acted upon by corrosion agent and other factors, as the days increase the more corrosion will take place on the carbon steel thereby reducing the weight of the carbon steel. Finding revealed that this technique is useful for the rate of corrosion of carbon steel, which is one of major issue in the aqueous environment (Chen et al., 2022; Jin et al., 2022; Liu and Shi, 2022; Mou et al., 2022).

CONCLUSIONS

An experiment on the rate of corrosion of carbon steel in three different aqueous environments (seawater, fresh water and alkaline solution) has been successfully carried out using the weight loss coupon technique. From the result obtained the following conclusion was made. Corrosion rate of carbon steel increase with time. The experiment shows that carbon steel immersed in seawater have the highest rate of corrosion than fresh water and alkaline solution at room temperature. The corrosion rate of carbon steel was very low in freshwater at room temperature of 25 °C. With increase in temperature, (25^{0}C - 35^{0}C) the corrosion rates increase. From the corrosion rate - exposure time (days) graph, it is possible to calculate an average corrosion rate for a particular exposure time and thereby obtain the corresponding corrosion extent.

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