



## Development of a New Type of Epoxy Coating for Crude Oil Storage Tanks

\*Haider H. Jasim<sup>a</sup>\*, Ala'aa A. Jasim<sup>a</sup>, Aziz H. Al-Hilfi<sup>b</sup>

<sup>a</sup>Chemical Engineering Department, Basrah University, Iraq.

<sup>b</sup>Materials Engineering Department, Basrah University, Iraq.

**Abstract:** A new type of epoxy coating characterized by containing both the hydroxyl group and amine group has been developed to provide protection for crude oil storage tanks. Corrosion behavior and flexibility were studied by using the immersion test method. The coating developed is slightly easier to apply and have 4:1 mix ratios of Base to Hardener. The coating was tested for evolution of corrosion resistance in the six various crude oils which collected from six fields (lower Zubair, upper Zubair, Nahr Umr, South Rumaila, North Rumaila and west Qurna,) which lie in Basrah city of southern Iraq. A mathematical model including the effect of pH and temperature was developed and applied in evolutions of the corrosion rate. The results of the corrosion tests towards coated carbon steel (ASTM A537) show that the coat develops had good resistance to crude oil corrosion and show best protection compared with other commercial (Jotun and Hempel) coatings which were tested in same crude oil solutions. The Lower Zubair crude oil field gives lower values of corrosion rate and west Qurna crude oil field give higher value and other fields show moderate values of corrosion rates.

**Keywords:** crude oil, epoxy coating, immersion test, corrosion rate, effective groups.

### I. Introduction

Crude oil is one of the most important raw materials for the production of energy and crude oil tanks play a strategic role in its storages. Corrosion is considered the most important factor leading to failures of tanks structures. There are many reasons for crude oil tanks to be effected by corrosion. Firstly, tanks are exposed to very corrosive conditions, crude oil when full; moist atmosphere when empty; cyclic heating and cooling from atmospheric exposure. Secondly, often comes from having large surface and highly stressed areas, such as corners, edges, and welded seam areas. Thirdly, tank coating is a very complex job with many ramifications [1].

Crude oil has a complex composition and it varies widely in their physical/chemical properties. Crude oils do not come out of the ground pure; there are always various by-products. Typically have a variety of impurities such as: water, CO<sub>2</sub>, H<sub>2</sub>S, various salts (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>... etc.) and organic acids. Oxygen (O<sub>2</sub>) is not present in produced fluids, but it can be introduced into the oil during the processing operations with fluids that are added. All these corrosive species lead to the corrosion in storage tanks. Various protection mechanisms to control the corrosion in crude oil tanks have been developed including barrier protection, corrosion inhibitors, and cathodic protection. The barrier protection deals with the disconnection of metal surface from the corrosive environment such as coatings on the metal surface using paint and epoxy coats [2].

Epoxy coat is one of the most common coating materials used in severe corrosion environments including crude oil environment. Due to the chemical groups of cured epoxy structure such as hydroxyl group (–OH), carboxyl group (C = O) and amino group (N–H) that have unpaired electron, epoxy has exhibited the superior properties when exposed to crude oil environment. The efficiency with which protection is provided is determined by a number of properties of the total coated system, which consists of the coatings film, the metal substrate, and it's pretreatment. The epoxy coating consists from two parts which are mixed shortly before use. The main component of part **A** (Base) is a epoxy molecule group containing two so called epoxy-groups, while the part **B** is a thinner (Hardener). When the two substances are mixed, a cross linked network is created, resulting in a hard substance that can be very strong [3].

In Iraq, the crude oil storage tanks are building and distributed over many regions. One of the most difficult problems occurring in these tanks are corrosion which causes in most cases lack and loss of crude oil which leads to pollutions of the environments and extra cost to the economy. Jotun and Hempel coatings have trade mark and are broader used as lining for oil tanks. These coating have high cost and need complicated during maintenance.

The research objective of present work is to develop an epoxy coat characterized by containing both the hydroxyl group and amine group, then tested in crude oil solutions collected from various fields located in

Basrah city of southern Iraq. Corrosions behavior and flexibility were studied by using immersion test method. The effect of temperature and pH values on corrosion rate of coating developed has been studied and evaluates. The corrosion rate of develop coats are compared with two types of coatings (Jotun and Hampel) that tested in same crude oil solution.

## II. Composition of the Coating Developed

Table1 and table 2 are list of components and amount of each of the component used for the Base and of that for the Hardener material used. The epoxy resin and the hardener are mixed together in 1:4 hardener/Base ratios. The ratio selected depended on the stoichiometry of the epoxy resin system. The amount and quantity of components is choice by trial and testing of various quantities and then choosing the best sample quantity and concentration.

**Table1 Compositions and amount of base components**

| Components                      | Quantity               |
|---------------------------------|------------------------|
| Phenol $C_6H_6O$                | 80 gm/l                |
| Phenol4,4'-(1-methylethylidene) | 300 ml                 |
| 2, 2'-(1- methylethylidene)     | 55 ml                  |
| bis (4, 1-phenylenoxymethylene) | 300 ml                 |
| oxirane $C_2H_4O$               | 1000ppm/100 ml solvent |
| m-xylene $C_6H_4(CH_3)_2$       | 45ml                   |
| Zinc phosphate $Zn_3P_2$        | 40 gm/l                |
| Benzyl alcohol $C_7H_8O$        | 120 ml                 |

**Table 2 Characteristic and concentration of thinner components**

| Components                          | Concentration |
|-------------------------------------|---------------|
| m-xylene $C_6H_4(CH_3)_2$           | 60 %          |
| solvent naphtha                     | 10 %          |
| light aromatic (Benzene)            | 7 %           |
| Polyamine<br>(triethylenetetramine) | 23 %          |

## III-Preparation and Coating of the Specimens

The test samples were cut from plate storage tank, carbon steel (ASTM A537) with the following compositions: Fe (97.58%), C (0.24%), Mn (0.035%), S (0.035%), Cr (0.025%), Si (0.5%), Mo (0.08%), Ni (0.25%), Cu (0.35%) [4]. The coupons have the dimensions of (25 x 50 x 6) mm for the purpose of immersion test. Test coupons were prepared in the engineering college machine shop. A hole was drilled in the middle of each specimen. The specimen were polished by using a different metallographic grade (180, 500, and 800) of emery paper then cleaned by distilled water and dried in a stream of air at room temperature. A total of 100 coupons were processed for testing. The coating was applied as coats and then it is left to dry for two weeks at room temperature and atmospheric pressure before being exposed to solution test. Figure 1, A and B show specimen before and after coating.



A-Before coating

B- After coating

**Figure 1 Specimen before and after coating with developed epoxy coating**  
**IV-Crude Oil Samples**

The crude oil samples were collected from six various fields located in the Basrah region (North Rumaila, South Rumaila, Upper Zubair, Lower Zubair, Nahr Umr and West Qurna). The crude oil heavy metals analysis using a spectrophotometer was carried at the Basrah Refinery laboratory, south oil company of Iraq. The other physical properties and dissolved gases are analyzed in chemical engineering laboratory of Basrah University, Iraq . Table 3 and table 4 show material composition, physical characteristic and dissolved gases of crude oil samples. The viscosity, specific gravity and dielectric constant of crude oils are measured laboratory and illustrated in table 5.

**Table 3 Material composition of different crude oils**

| Field<br>Metals ppm wt | North Rumaila | South Rumaila | Zubair - Upper | Zubair - Lower | Nahr - Umr | West-Qurna |
|------------------------|---------------|---------------|----------------|----------------|------------|------------|
| Iron                   | 3             | 1.4           | 2.25           | 1.6            | 2          | 7          |
| Copper                 | 5             | 7             | 0.8            | 0.2            | 9          | 14         |
| Vanadium               | 43            | 55.7          | 40.1           | 31             | 49         | 62         |
| Nickel                 | 8.2           | 11            | 10             | 8.7            | 10.5       | 9.8        |
| Cadmium                | 0.1           | 0.17          | 0.64           | 0.02           | 2          | 3          |
| Zinc                   | 0.13          | 0.07          | 0.41           | 0.04           | 0.08       | 0.89       |
| Aluminum               | 0.2           | 0.16          | 0.11           | 0.03           | 0.06       | 0.09       |
| Manganese              | 0.10          | 0.07          | 0.04           | 0.02           | 0.03       | 0.18       |

**Table 4 Physical properties of crude oils**

| Field<br>Property         | North Rumaila | South Rumaila | Zubair Upper | Zubair Lower | Nahr Umr | West-Qurna |
|---------------------------|---------------|---------------|--------------|--------------|----------|------------|
| API                       | 33.8          | 30.2          | 34.3         | 34.1         | 33.6     | 32.31      |
| Carbon residue %          | 7.3           | 6.33          | 5.99         | 3.95         | 3.1      | 8.4        |
| Sulfur %                  | 3.9           | 2.92          | 2.95         | 1.1          | 2.1      | 4.3        |
| Water content % by volume | 1             | 0.75          | 0.8          | 0.2          | 0.6      | 0.9        |
| N <sub>2</sub> (g) %      | 0.13          | 0.98          | 0.08         | 0.09         | 0.81     | 0.79       |
| TAN mgKOH/gm oil          | 0.37          | 0.112         | 0.2          | 0.06         | 0.11     | 0.333      |
| Salt NaCl ppm             | 14            | 13            | 11           | 3.8          | 5        | 10.81      |
| Asphaltenes %             | 2.2           | 1.45          | 1.2          | 0.5          | 0.77     | 0.94       |
| H <sub>2</sub> S (g) ppm  | 1.1           | 1             | 2            | 0.7          | 1        | 1.5        |
| CO <sub>2</sub> (g) ppm   | 3             | 3             | 2            | 2            | 2.3      | 3.5        |
| O <sub>2</sub> (g) %      | 1             | 1.1           | 0.9          | 0.9          | 0.9      | 1.1        |

**Table 5 Viscosity, specific gravity and dielectric constant of crude oils**

| Property            |      | Fields        |               |              |              |          |            |
|---------------------|------|---------------|---------------|--------------|--------------|----------|------------|
|                     |      | North Rumaila | South Rumaila | Zubair Lower | Zubair Upper | Nahr Umr | West Qurna |
| Viscosity (cst)     | 40°C | 12.1          | 17.6          | 5.8          | 9.8          | 16       | 28.3       |
|                     | 50°C | 11.4          | 13.8          | 5.3          | 9.1          | 15.8     | 21.2       |
|                     | 60°C | 8.6           | 12.1          | 4.5          | 6.7          | 11.9     | 16.4       |
| Specific gravity    | 40°C | 0.8860        | 0.8952        | 0.8745       | 0.9047       | 0.8572   | 0.9073     |
|                     | 50°C | 0.8801        | 0.8707        | 0.8702       | 0.8902       | 0.8503   | 0.8973     |
|                     | 60°C | 0.8533        | 0.8648        | 0.8678       | 0.8813       | 0.8433   | 0.8854     |
| Dielectric constant | 40°C | 2.414         | 2.261         | 1.921        | 1.988        | 2.102    | 2.509      |
|                     | 50°C | 2.353         | 2.207         | 1.864        | 1.945        | 2.006    | 2.492      |
|                     | 60°C | 2.305         | 2.152         | 1.833        | 1.892        | 1.989    | 2.432      |

### V-Apparatus and Test Procedure

The equipment used for the experiment are three water baths, Beakers 500ml., sensitive weighting balance, Digital pH meter, long pin and nylon thread for suspended the specimens in beakers. A computerize Carl Zeiss Jena imaging system, using microscope provided by camera smart technical have (22 Mega pixels) used to photo the surface of specimen before and after test. The apparatus are shown in figure 4.

After taking the initial weight of the coated coupons, the coupons were suspended inside the 500 ml Beaker containing crude oil solution balanced with 10% NaOH and 0.1N HCl solution to obtain the pH value of the crude oil solutions are equal to 5, 6 and 7. Immersion test was carried out at a set of temperature range between (40°C to 60°C). The temperature is regulated using water bathes, for an exposure period of 180 days. After each 15 day of coated coupon immersion, the coupons were extracted from the crude oils and cleaned, then weighed. The corrosion rate is calculated assuming uniform corrosion over the entire surface of the coupon in (mm/year) using the expression [5]:

$$CR = \frac{8.76 \times 10^4 \Delta W}{\rho A_s t} \quad \dots (1)$$

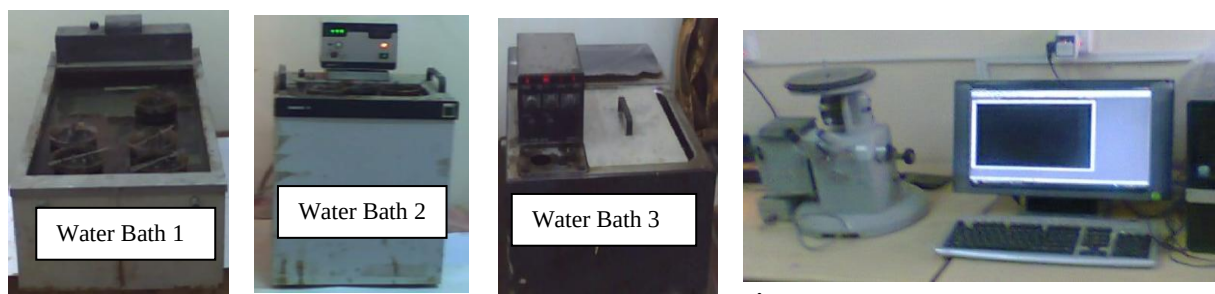


Figure 2. Water Baths and Computer Imaging systems  
VI- Mathematical Model Developed

The theoretical values of corrosion rate can be calculated from anodic and cathodic reactions as follows:

#### A- Anodic Reaction Description

The mechanism of anodic dissolution of iron has been extensively investigated in acid solutions; the dependence of the dissolution rate on the activity of hydroxyl ion is generally accepted. The mechanism proposed by Bockris *et. al.* [6] is as follows:



The current density for the Fe dissolution is given by:

$$i_{\text{Fe}} = i_{\text{Fe}}^0 e^{(-1.5F(E - E_{\text{Fe}}^0)/RT)} \quad \dots (5)$$

The exchange current density can be expressed as follows [7]:

$$i_{\text{Fe}}^0 = i_{\text{Fe}}^0 \text{a}_{\text{OH}}^{1.6} \text{a}_{\text{H}_2\text{O}} \quad \dots (6)$$

The reversible potential is calculated from the Nernst equation and depends on the concentration of  $(\text{Fe}^{+2})$  ions as follow:

$$E = E^0 - \frac{RT}{ZF} \ln [\text{Fe}^{+2}] \quad \dots (7)$$

#### B-Cathodic Reaction for $\text{CO}_2$

In  $\text{CO}_2$  corrosion cathodic process may be due to the reaction of four separate species i.e.  $\text{H}^+$ ,  $\text{OH}^-$ ,  $\text{H}_2\text{O}$  and  $\text{H}_2\text{CO}_3$ , in acidic solution the reduction of  $\text{H}^+$ , is the dominant cathodic reaction [6]:



According to the basic electrochemical kinetics the current density for  $\text{H}^+$  reduction can be written as [7]:

$$\frac{1}{i_{\text{H}}} = \frac{1}{i_{\text{H},a}} + \frac{1}{i_{\text{H},\text{lim}}} \quad \dots (9)$$

The activation current density for the reduction portion can be written as follows:

$$i_{\text{H},a} = i_{\text{H}}^0 e^{(-0.5F(E - E_{\text{H}}^0)/RT)} \quad \dots (10)$$

So, the exchange current density is given by Smart and Bockris [5]:

$$i_{\text{H}}^0 = i_{\text{H}}^0 \text{a}_{\text{H}}^{0.5} \text{a}_{\text{H}_2\text{O}}^{2.2} \quad \dots (11)$$

The limiting current densities Eq.22 can be calculated as:

$$i_{\text{H},\text{lim}} = K_m \text{Fa}_{\text{H}} \quad \dots (12)$$

Where, the values of  $K_m$  can be calculated if the flow regime, diffusion coefficient of  $\text{H}^+$  ions and solution viscosity are known.

In addition to the reduction of  $\text{H}^+$  ions, the direct reduction of water is also considered, i.e. [6]:



The water reduction does not have limiting current density because there are no diffusion limitations for the transport of H<sub>2</sub>O molecules to the surface. Thus the current density can be express as:

$$i_{H_2O} = i_{H_2O}^0 e^{(-0.5F(E-E_H^0)/RT)} \quad \dots (14)$$

Thus the exchange current density is given by the following equation [7]:

$$i_{H_2O}^0 = i_{H_2O} (a_H)^{-0.5} (a_{H_2O})^{2.2} \quad \dots (15)$$

At (pH > 4) reduction of carbonic acid (H<sub>2</sub>CO<sub>3</sub>) becomes the dominant cathodic process and carbonic acid results from the hydration of dissolved CO<sub>2</sub>, i.e.



The H<sub>2</sub>CO<sub>3</sub> reduction is under chemical reaction control so,

$$\frac{1}{i_{H_2CO_3}} = \frac{1}{i_{H_2CO_3,a}} + \frac{1}{i_{H_2CO_3,lim}} \quad \dots (17)$$

The activation current is given by [12]:

$$i_{H_2CO_3,a} = i_{H_2CO_3}^0 e^{(-\alpha_{H_2CO_3} F(E-E_H^0)/RT)} \quad \dots (18)$$

The exchange current density for H<sub>2</sub>CO<sub>3</sub> reduction can be expressed as:

$$i_{H_2CO_3}^0 = i_{H_2CO_3} a_{H_2CO_3} a_H^{0.5} \quad \dots (19)$$

Following Nesic et. al. [8] the limiting current density can be expressed as follows:

$$i_{H_2CO_3,lim} = F a_{H_2CO_3} * \left( D_{H_2CO_3} K_{H_2CO_3} K_{H_2CO_3}^f \right)^{0.5} \quad \dots (20)$$

Where,

$$D_{H_2CO_3} = 10^{-5} \text{ cm}^2 / \text{s} \quad , \quad K_{H_2CO_3} = 1.7 * 10^{-3}$$

The values of K<sub>H<sub>2</sub>CO<sub>3</sub></sub><sup>f</sup> at any temperature are calculated from the expression developed by Nesic et al. [8]:

$$K_{H_2CO_3}^f = 10^{169.2 - 53 \text{Log}(T) - \left[ \frac{11715}{T} \right]} \quad \dots (21)$$

For all partial process the generalized Arrhenius equation can be expressed as follows [8]:

$$i_T^* = i_{T_0} \exp \left[ \frac{-\Delta G}{RT} \left( \frac{1}{T} - \frac{1}{T_0} \right) \right] \quad \dots (22)$$

And the applied current density (i<sup>\*</sup>) is:

$$i^* = \frac{zA\gamma_a}{A_w} \exp \left( \frac{-\Delta G}{RT} \right) \quad \dots (23)$$

According to mixed potential theory:

$$\sum I_{cathode} = I_{anode} = I_{corr}. \quad \dots (24)$$

Faraday's law used to calculate the corrosion rate (CR) in mm/year for uniform corrosion as follows [9]:

$$CR = 3.27 * 10^{-3} * \frac{I_{corr}}{\rho_m} E_w \quad \dots (25)$$

### C- Calculation of crude oil activity

Bromley, show a method for the calculating of activity coefficient as followers [10]:

$$\log \gamma_i = \frac{-A_d |Z_+ Z_-| \sqrt{I}}{1 + \sqrt{I}} + \frac{(0.06 + 0.6 B_{ij}) |Z_+ Z_-|}{\left( 1 + \frac{1.5}{|Z_+ Z_-| I} \right)^2} I + B_{ij} I \quad \dots (26)$$

$$\text{Where, } I = \frac{1}{2} \sum m_i Z_i^2, \quad A_d = \frac{\sqrt{2\pi N_A \rho}}{3} \left( \frac{e}{\sqrt{4\pi * D_i * \epsilon_r * k_B T}} \right)^3 \quad \text{AND} \quad B = B^+ + B^- + \delta^+ \delta^-$$

The coefficients for the Bromley equation are given in table 6.

**Table 6 the Bromley ion specific parameter [10]**

| Cation                       | B <sup>+</sup> | $\delta^+$ | Anion                        | B <sup>-</sup> | $\delta^-$ |
|------------------------------|----------------|------------|------------------------------|----------------|------------|
| H <sup>+</sup>               | 0.0875         | 0.103      | Cl <sup>-</sup>              | 0.0643         | - 0.06     |
| Na <sup>+</sup>              | 0.0            | 0.028      | NO <sub>3</sub> <sup>-</sup> | - 0.025        | 0.27       |
| K <sup>+</sup>               | - 0.0452       | - 0.079    | SO <sub>4</sub> <sup>-</sup> | 0.0            | - 0.4      |
| NH <sub>4</sub> <sup>+</sup> | - 0.042        | -0.02      | CO <sub>3</sub> <sup>-</sup> | 0.028          | - 0.67     |
| Ca <sup>+2</sup>             | 0.0374         | 0.119      |                              |                |            |
| Al <sup>+3</sup>             | 0.052          | 0.12       |                              |                |            |
| Mn <sup>+2</sup>             | 0.037          | 0.21       |                              |                |            |
| Mg <sup>+2</sup>             | 0.057          | 0.157      |                              |                |            |

## VII-Results and Discussion

For investigation and developing a new coating, the two material Phenol4,4'-(1-methylethylidene)bis and bis(4,1-phenylenoxymethylene) are reaction together to form the basis of the first type of epoxy and reaction between the (triethylenetetramine) of epoxy curing agent with the polyamine containing primary amine functionality and this forms the second type of epoxy called (polyamine adduct). The mixing process is achieved using a mixer for two hour to take enough time for components to mix with other and the homogenous solution will obtained.

The reaction between polyamine and epoxy resin is yielded polyamine epoxy resin adduct (polyamine adduct). This product contained high equivalent mass polyamine resin adduct with less reactivity. Oxirane (ethylene oxide) used for making a consumed product as well as non consumed chemicals and intermediate. The reason for using two different types of epoxy during the preparation is to increase the stability, improve the properties at high temperatures and increasing adhesion to the steel surface.

Zinc phosphate is an inorganic chemical compound that is added to increase the corrosion resistance and increase the bonding of an epoxy coating with metal. Benzyl alcohol is an organic compound used as a solvent for the epoxy resin coating.

The hardener consists from m-xylene, solvent naphtha, light aromatic, and Polyamine. The epoxy resin and the hardener prepared are mixed together in 1:4 Hardener/Base ratios. When these compounds are mixed with an epoxy resin, both amine groups and hydroxyl group react with the epoxy groups to form a covalent bond and the resulting coatings is heavily cross linked, and is thus rigid and strong. The drying time is about two weeks. The two effective groups (hydroxyl group and amine group) that produce increase adhesion and cohesion properties.

The immersion test was conducted to determine the corrosion rate using the weight loss method in which coated coupons with the epoxy developed initially weighed and then exposed to the crude oil solution for a specified period of time.

Figures 3 A to F, show the comparisons of the general corrosion rate obtained from the experimental immersion test and mathematical method as a function of temperature for both uncoated coupon and coated with the developed coating. The mathematical calculation of corrosion rate of uncoated coupons is achieved according to approaches that developed. As indicated the experimental rate of corrosion for uncoated coupon is high compared to mathematical calculation and it has small values after coating. As temperature increases, the mathematical calculating and experimentally corrosion rate obtain are increased.

Figures 4 and 5 show the corrosion rate in (mm/year) vs. time in (days) obtained from an immersion test of the coating developed in the six types of crude oil solutions. The exposure time is 180 days to which provide a sufficient time for the chemical corrosion to take place. These figures are clearly demonstrating that there are a large difference between the corrosion rates for the coating develops that was tested in each types of crude oil. The corrosion rates naturally increases with an increasing time. Both pH and temperature have effected the corrosion rates. Increasing the temperature of crude oil will normally have the effect of increasing the corrosion rates. Since increasing temperatures leadings to high speed of electron transfer and coating dissolution in crude oil solutions. The pH value of crude oil effect solubility of the corrosion products. As indicated from these figures, the lower Zubair crude oil has the lowest values of corrosion rates while the west Qurna crude oil has large values of the corrosion rates. The other types of crude oil show moderate values between these results. This is attributed to the effect of many factors that influence the crude oils such as: impurities, dissolved gases including CO<sub>2</sub>, H<sub>2</sub>S, O<sub>2</sub>, water chemistry and salts in the crude oils.

Figure 6 shows the microscopic examination of the developed epoxy coat coupon before and after an immersion test in the lower Zubair crude oil at pH = 5 and T = 50°C. Samples were photographed using metallographic microscope with magnification of 10X. Morphology examinations indicated after immersion

test, there are some pits on the coated surface of the coat coupon and degradation in coating, besides, the color of the surface is found to be changes.

The different concentration of water and dissolved gases of crude oil samples make it different in corrosion effects. In general, increase of water concentration increases the corrosion rate. As seen from crude oil composition, the water percent of lower Zubair fields is the lowest value while the West Qurna and North Rumaila have the large values. This attributed as believe that West Qurna field is near the Euphrates river that passed through field and middle it into two parts phase1 and phase2, while lower Zubair and upper Zubair field lays in desert regions.

The lower Zubair field contains low sulfur and high asphalt. The presence of asphalt in the crude oil causes a reduction in corrosion rate and as the concentration of asphalt increases the corrosion rate decreases. An asphalt forms a strong protective layer on the steel surface which acts as a barrier for corrosive agents and reduces the corrosion. West Qurna Crude oils contain high concentrations of sulphur constituents and this can cause high levels corrosion when these components react with water to form acidic compounds. Sulphur is cathodic by nature and can promote the formation of an active corrosion cell

Figure 7 shows comparison between developed coating and commercial Jotun and Hampel coating manufactured by Sharja Company, United Arab Emirates, which used in Iraq in a broader range. As indicate that the best protection was provided by the develop coatings which exhibit low corrosion losses, and provide better overall performance than the other coatings and deemed a viable corrosion control system. Whereas Hampel coating exhibits the greatest amount of weight loss due to corrosion. This is attributed to the composition of the coatings and reactivity of the effective groups found. The effective hydroxyl and amine group in developed coatings strongly improves the barrier properties and lowers the permeability of dissolved gases. The effective groups are initiate high links covalent through material coats which make the components are very cohesive, decreased the porosity and increase hardness, this lead to increased resistance to corrosion rates under various temperature and pH values.

### VIII - Conclusions

From the previous discussion the following remarks can be concludes:

- 1- Good agreements obtained from both mathematical and experimental immersion test method for uncoated coupon under different temperature and pH values.
- 2- Developed, Jotun and Hampel coatings show good resistance to crude oil solution, but Hampel show large corrosion rates compared with others coatings that tested.
- 3- The lower Zubair petroleum has lower rate of corrosion while west Qurna petroleum has the large value of corrosion rate this due to composition of each types of petroleum.
- 4-The developed coating was excellent with good adherence and cohesion strength as observed prior to and after exposure to crude oil solution.

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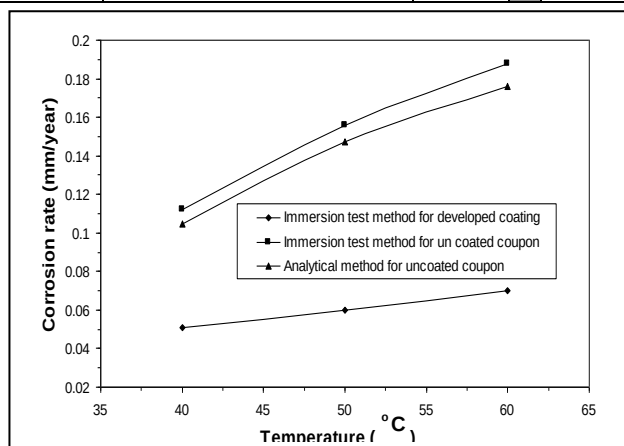
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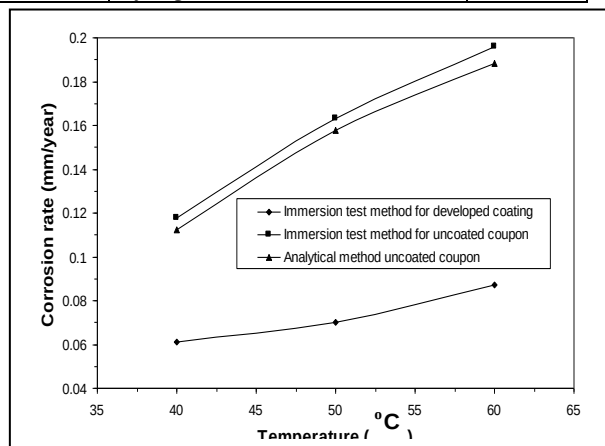
### Nomenclature

|                    |                           |                  |                |                        |     |
|--------------------|---------------------------|------------------|----------------|------------------------|-----|
| A <sub>s</sub>     | Exposed specimen area     | cm <sup>2</sup>  | K <sub>b</sub> | Boltzman constant      | J/K |
| i <sub>0</sub>     | Exchange current density  | A/m <sup>2</sup> | Z <sub>i</sub> | Valance of ion i       | -   |
| I <sub>corr.</sub> | Corrosion current density | A/m <sup>2</sup> | D <sub>i</sub> | Dielectric constant    | -   |
| E                  | Electrode potential       | V                | t              | Immersion exposed time | hr. |
| E <sub>eq</sub>    | Equilibrium potential     | V                | Δ W            | Mass loss              | g   |
| K <sub>m</sub>     | Mass transfer coefficient | cm/s             | I              | Ionic strength         | -   |

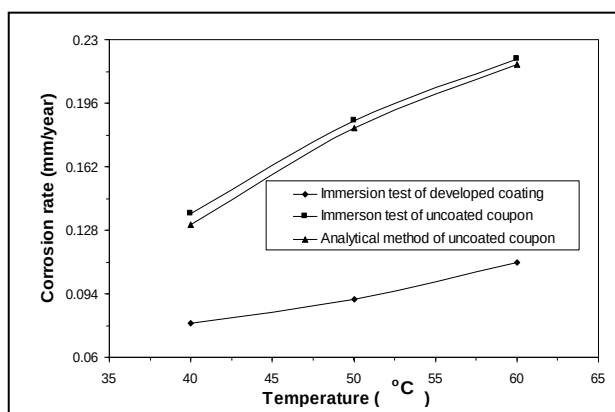
|            |                         |   |                     |                                            |                    |
|------------|-------------------------|---|---------------------|--------------------------------------------|--------------------|
| F          | Faraday constant        | - | $E_w$               | Equivalent weight                          | -                  |
| R          | Universal gas constant  | - | $A_w$               | Atomic weight of element                   | g/mol              |
| $N_A$      | Avogadro number         | - | $\epsilon_r$        | Permittivity in vacuum                     | $C^2/J.m$          |
| T          | Applied Temperature     | K | $\rho_c$            | Density of crude oil                       | $Kg/m^3$           |
| $T_o$      | Reference temperature   | K | $\Delta G$          | Free energy charge                         | kJ/mol             |
| $A_d$      | Debye-Huckel constant   | - | $\alpha$            | Symmetry coefficient                       | -                  |
| $B^+, B^-$ | Bromly constants        | - | $\rho$              | Density of coupon                          | -Kg/m <sup>3</sup> |
| $Z^+, Z^-$ | cation and anion charge | - | $a_{OH^-}, a_{H^+}$ | Activity of hydroxyl ion and hydrogen ion, | -                  |



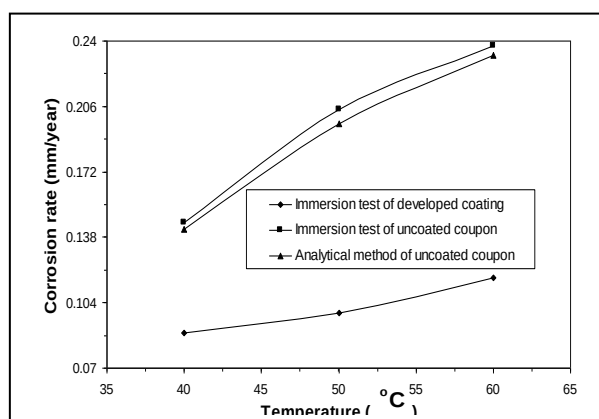
A



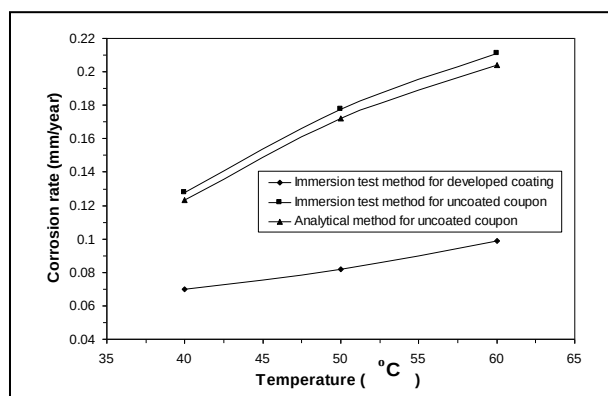
B



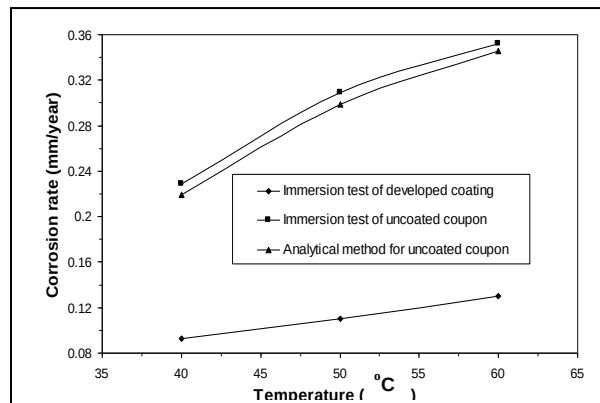
C



D



E



F

Fig. 3 Comparison between analytical and experimental method at pH = 5 and different temperature for developed epoxy coating for: A- Lower Zubair B- Upper Zubair C – South Rumaila D- North Rumaila E - Nahr Umr F-West Qurna crude oil.

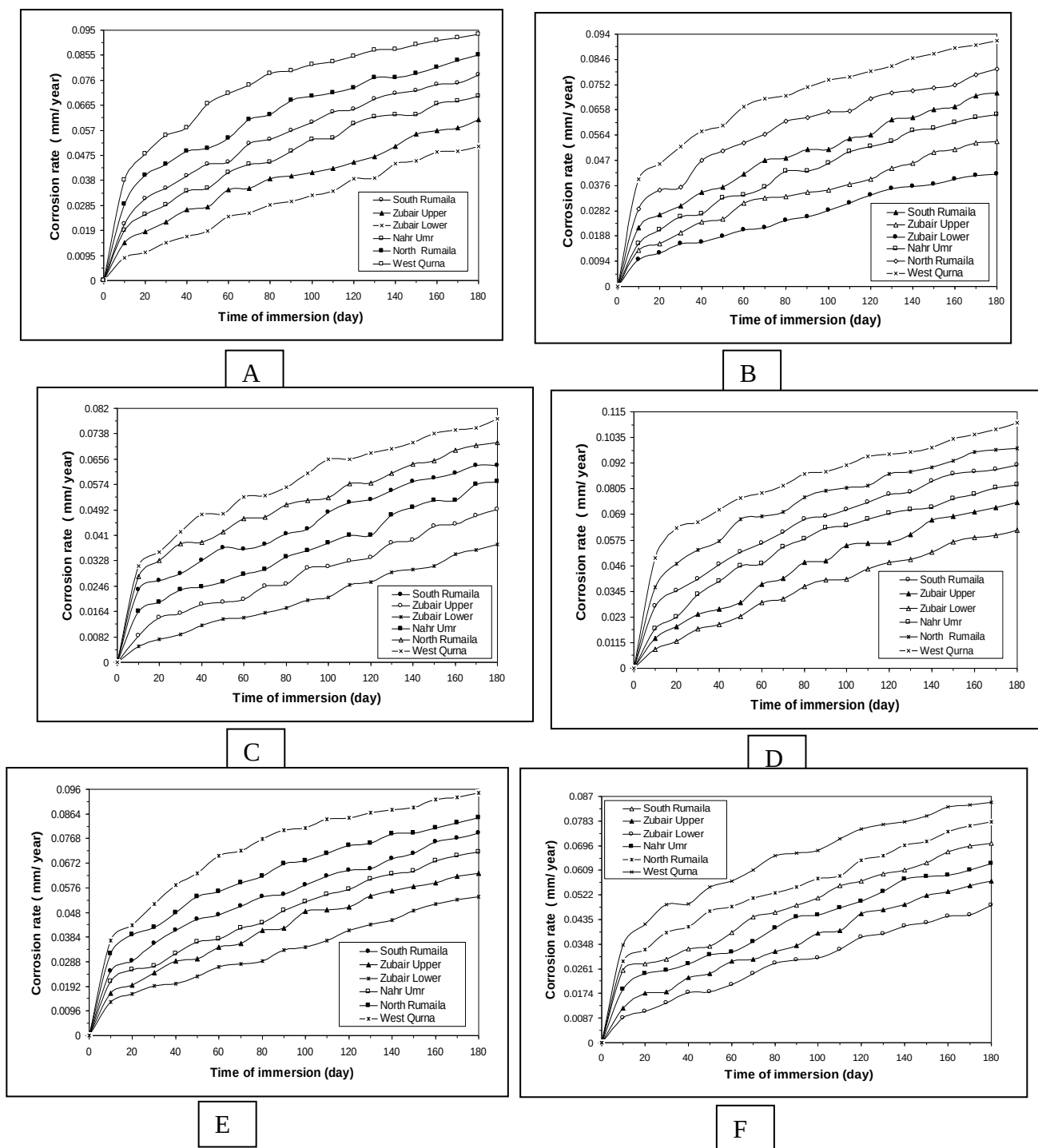


Fig. 4 Comparison the corrosion rate vs. time obtained from immersion test for different crude oil at  
A- pH = 5 , T = 40°C    B- pH = 6 , T = 40°C    C- pH = 7 , T = 50°C    D- pH = 5 , T = 50°C  
E- pH = 6 , T = 50°C    F- pH = 7 and T = 50°C for developed coating

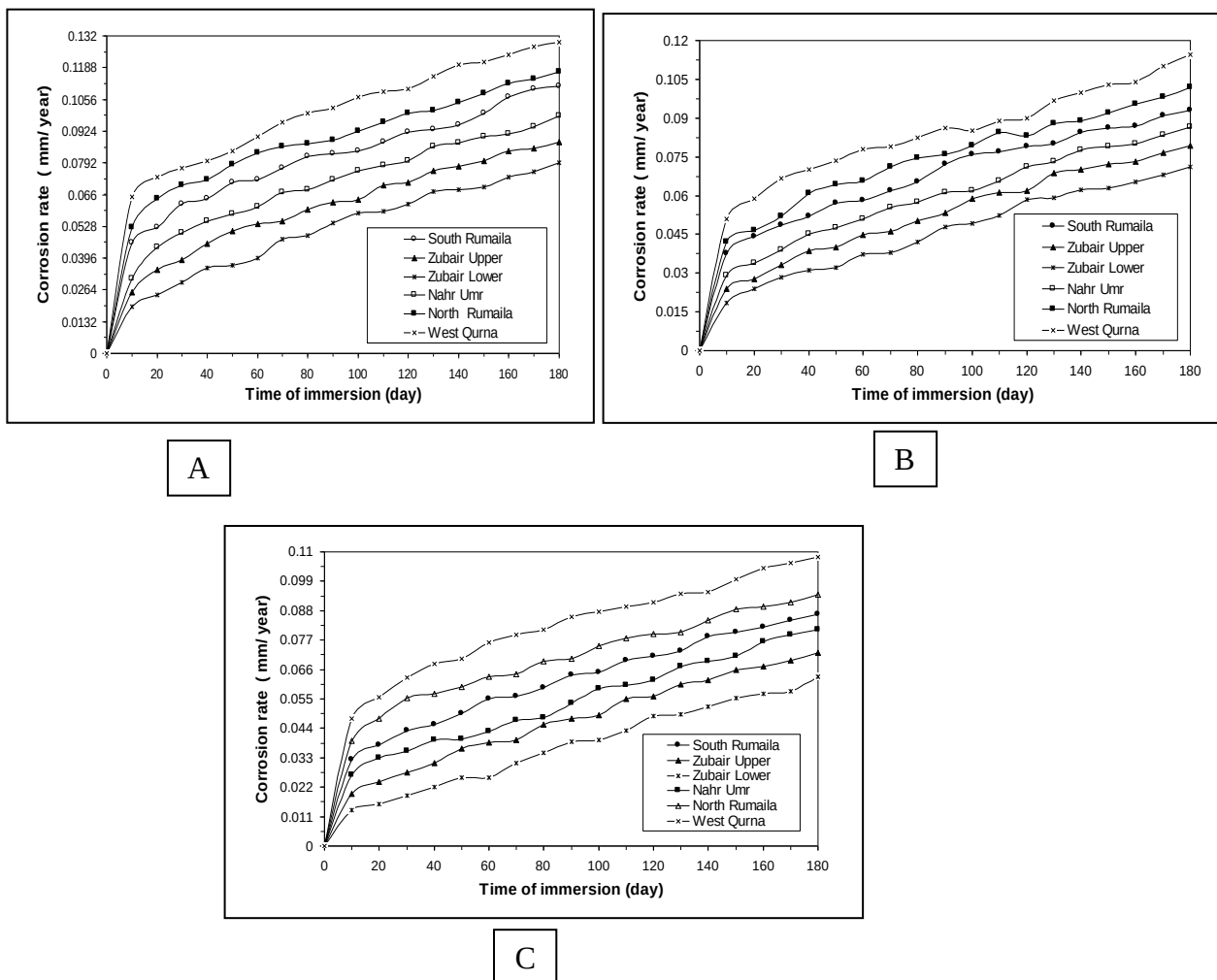


Fig. 5 Comparison the corrosion rate vs. time obtained from immersion test for different crude oil at  
A- pH = 5 , T = 60°C B- pH = 6 , T = 60°C C- pH = 5 , T = 60°C for developed coating

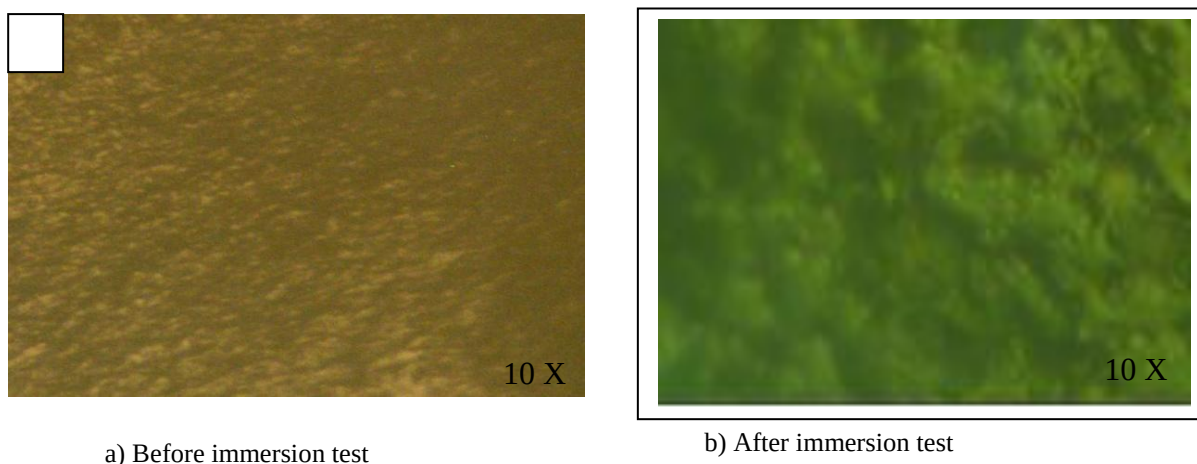


Fig.6 Surface morphologies for develop coat a) before immersion test  
b) after immersion test in lower Zubair crude oil at pH = 5 and T = 50°C.

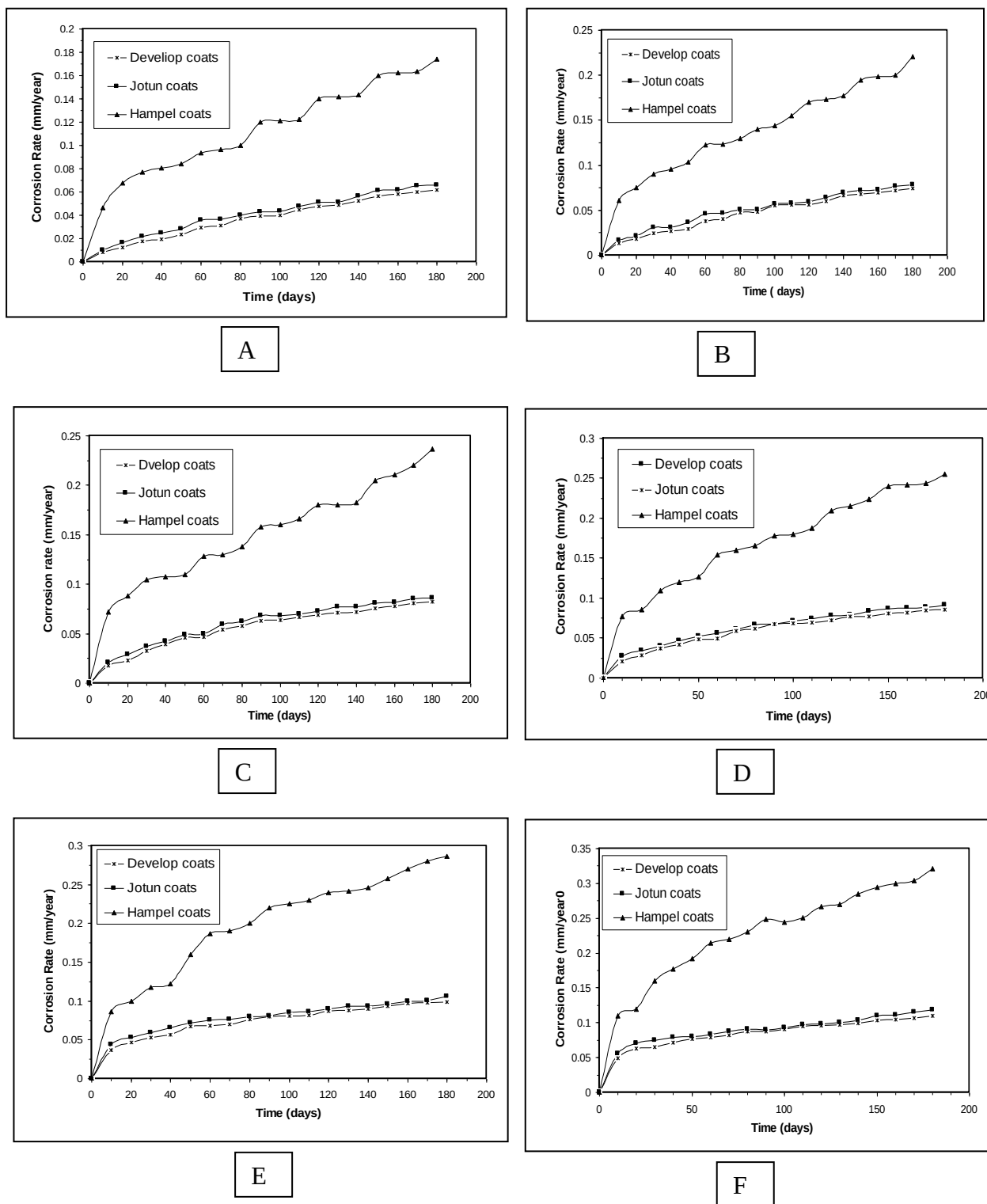


Fig.7 Comparison between coating developed with Jotun and Hampel coatings after test at pH = 5 and T= 50°C in A- lowe Zubair B- upper Zubair C- Nahr Umr D- south Rumaila E- north Rumail F- west Qurna