Inhibition of corrosion of mild steel in well water by TiO$_2$ nanoparticles and an aqueous extract of May flower

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Titanium dioxide nanoparticles have been used to control corrosion of mild steel in well water in the absence and presence of an aqueous May flower extract. As the concentration of TiO$_2$ increases, the inhibition efficiency also increases. 100 ppm of TiO$_2$ offers 84% inhibition efficiency. The addition of 10ml of May flower extract enhances the inhibition efficiency to 95%. Adsorption of TiO$_2$ on the metal surface follows Langmuir adsorption isotherm. Polarization study reveals that the flower extract-TiO$_2$ system functions as mixed type of inhibitor, controlling both anodic and cathodic reactions. AC impedance spectra reveal the formation of a protective film on the metal surface. This technology may find application in cooling water systems and concrete technology.

Keywords: corrosion inhibition, nanoparticles, TiO$_2$, flower extract, Delonix regia, adsorption isotherm.

1. Introduction

Nanotechnology is an emerging field through which new productions on nano scale can be manufactured. Producing a new generation of textiles which possess antimicrobial properties using nanoparticles has attracted a great deal of attention from both scientists and consumers in recent years [1, 2]. Furthermore, metal nanoparticles show unique properties due to their peculiar electronic configuration, very large surface area and high amount of surface atoms [3]. For instance, metal nanoparticles show a broad absorption band in the visible region of the electromagnetic spectrum [4]. Some amazing properties of metals are used in order to improve the photocatalytic activities of semiconductors, such as TiO$_2$ and SiO$_2$, which are among the most efficient ones, resulting in better photocatalytic properties, even under visible rays [5]. Some noble metals, such as Ag [6], Au [7] and Pd [8] have stood the test of time in the field of producing nanocomposites.

Several nanoparticles have been used as corrosion inhibitors. As the particle size decreases, the inhibition efficiency increases because the surface area covered by the nanoparticles on the metal’s surface increases. Nano-TiO$_2$ particles have improved the corrosion resistance of carbon steel [9], Ni-base alloys [10], aluminum surface [11]. A TiO$_2$ nanoparticle coating has been used to prevent biofilm formation in water and wastewater installations. Copper nanoparticles have improved the corrosion inhibition efficiency of carbon steel. Titanium dioxide (TiO$_2$) is a very promising metal oxide which has been widely studied as a photocatalyst for organic synthesis [12] and environmental cleaning processes [13]. Recent applications, based on the photocatalysis and photoactivity of TiO$_2$, include anti-fouling, antibacterial, deodorizing and self-cleaning functions [14]. In close connection with the developments in academic research, TiO$_2$ photocatalysis technology has also become more attractive in industrial applications due to its effectiveness, availability, low cost and chemical stability [15].

In this work, TiO$_2$ nanoparticles were prepared using commercially available titanyl chloride solution and characterization studies by SEM, EDS. The corrosion resistance of mild steel in well water in the presence of titanium dioxide nanoparticles and an aqueous extract of may flower (Delonix regia) by weight loss method, polarization study and AC impedance spectra.
2. Experimental methods

2.1. Preparation of TiO$_2$ nano particles

**Stage 1:** 50 g of titanium tetrachloride of AR grade was chilled in a freezer overnight and placed in a 500 ml flask. To this, 250 ml of deionized ice water was added drop-wise while continuously shaking the flask. The reaction produced an aqueous titanyl chloride.

**Stage 2:** The titanyl chloride solution was then added dropwise to a solution of 10 ml glycolic acid (Merck, 70 %) in a flask. Deionized water was added dropwise until a total volume of 300 ml was reached, while continuously shaking the flasks.

**Stage 3:** The precursor solution was then allowed to stand for 15 days at room temperature, until white precipitates formed. The precipitates were filtered using a pressure filtration unit and then washed with water and methanol [16].

2.2. SEM and EDAX spectra

A few drops of the solution containing TiO$_2$ nanoparticles were dried on a glass plate. The solid mass was used for recording SEM and EDAX. SEM and EDAX were recorded in field Emission Scanning Electron Microscopy (FESEM-SUPRA 5S)-(ARLZEISS, GERMANY).

2.3. Preparation of the specimen

Mild steel specimens (0.026 % S, 0.06 % P, 0.4 % Mn, 0.1 % C, and the rest iron) of the dimensions 1.0 cm × 4.0 cm × 0.2 cm were polished to a mirror finish and degreased with trichloroethylene and used for the weight loss method and surface examination studies.

2.4. Preparation of May flower extract

An aqueous extract of May flower (*Delonix regia*) was prepared by grinding 10 g of flower using sterile mortar and pestle, filtered through three layers of muslin cloth and make up to 100 ml using double distilled water. This aqueous extract was used as corrosion inhibitor. The image of May flower are shown in Fig. 1.

![May flower](image)

**Fig. 1.** May flower

2.5. Determination of corrosion rate

The weighed specimens in triplicate were suspended by means of glass hooks in 100 ml of well water containing various concentration of TiO$_2$ nanoparticles in the presence and absence of may flower extract (FE) for one day. The specimens were taken out, washed in running water, dried, and weighed. From the change in weights of the specimens, corrosion rates were calculated using the following relationship:

$$CR = \frac{[(Weight\ loss\ in\ mg)/(Area\ of\ the\ dspecimens\ in\ dm^2 \times\ Immersion\ periods\ in\ days)]}{mdd}. \quad (1)$$

Corrosion inhibition efficiency (IE %) was then calculated using the equation:

$$I.E. = 100[1 - (W_2/W_1)]\%,$$

where, $W_1$ – corrosion rate in the absence of the inhibitor, and $W_2$ – corrosion rate in the presence of the inhibitor.
2.6. Potentiodynamic polarization

Polarization studies were carried out in a CHI – Electrochemical workstation with impedance, Model 660A. A three-electrode cell assembly was used. The three electrode assembly is shown in Fig. 2. The working electrode was mild steel. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode. From the polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}) and Tafel slopes (anodic = b_a and cathodic = b_c) and Linear polarization resistance (LPR) were calculated. The scan rate (V/S) was 0.01 and the hold time at (E_{fcs}) was zero and quit time(s) was two.

![Circuit diagram of three-electrode cell assembly. WE- working electrode (mild steel), RE-Reference electrode (saturated calomel electrode (SCE)), CE- Counter electrode (platinum)](image)

2.7. AC impedance spectra

AC impedance spectral studies were carried out in a CHI – Electrochemical workstation with impedance, Model 660A. A three-electrode cell assembly was used. The working electrode was mild steel. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode. The real part (Z') and imaginary part (Z'') of the cell impedance were measured in ohms at various frequencies. Values of the charge transfer resistance (R_t) and the double layer capacitance (C_dL) were calculated.

3. Results and Discussion

3.1. Characterization of TiO_2 nanoparticles

The TiO_2 nanoparticles have been synthesized. The SEM image of the TiO_2 nanoparticles is shown in Fig. 3. The quantitative results for TiO_2 are shown in Fig. 4.

3.2. Analysis of EDS

EDAX spectrum of TiO_2 nanoparticles is shown in Fig. 5. The data derived from the spectra are given in Table 1. The processing option during recording the spectrum was normalized (all elements were analyzed). The number of iterations was 3. The following standards were used: carbon – CaCO_3; oxygen – SiO_2; titanium – Ti. The size of TiO_2 nanoparticles is shown in Fig. 6. The size of TiO_2 nanoparticles was shown to range from 70 – 90 nm.

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>9.03</td>
<td>22.90</td>
</tr>
<tr>
<td>Ti K</td>
<td>90.97</td>
<td>77.10</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>
FIG. 3. The SEM image of TiO₂ nanoparticles

FIG. 4. The quantitative results of TiO₂ nanoparticles

FIG. 5. EDAX spectrum of TiO₂ nanoparticles
4. Weight loss method

4.1. Corrosion inhibition by TiO$_2$ system

Corrosion rates (CR) of mild steel immersed in well water (WW) in the absence and presence of TiO$_2$ and the inhibition efficiencies (IE) obtained by weight loss method are given in Table 2. It was observed that when 100 ppm of TiO$_2$ was added to well water, the corrosion rate decreases to a great extent; and an inhibition efficiency of 80% was obtained. This is due to the adsorption of TiO$_2$ nanoparticles on the metal’s surface. As the concentration of TiO$_2$ increases, the corrosion rate decreases and the inhibition efficiency increases (Fig. 7) [17–20].

<table>
<thead>
<tr>
<th>TiO$_2$ Ppm</th>
<th>CR mdd</th>
<th>IE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>23.45</td>
<td>-</td>
</tr>
<tr>
<td>0</td>
<td>13.93</td>
<td>41</td>
</tr>
<tr>
<td>40</td>
<td>11.26</td>
<td>52</td>
</tr>
<tr>
<td>60</td>
<td>7.50</td>
<td>68</td>
</tr>
<tr>
<td>80</td>
<td>6.80</td>
<td>71</td>
</tr>
<tr>
<td>100</td>
<td>4.69</td>
<td>80</td>
</tr>
</tbody>
</table>

TABLE 2. Corrosion rates (CR) of mild steel immersed in well water (WW) in the absence and presence of TiO$_2$ and the inhibition efficiencies (IE) obtained by the weight loss method

Fig. 6. The size of TiO$_2$ nanoparticles

Fig. 7. Correlation between concentration of TiO$_2$, corrosion rate and inhibition efficiency
4.2. Corrosion inhibition by May flower extract (FE) system

Corrosion rates (CR) of mild steel immersed in well water (WW) in the absence and presence of May flower extract and the inhibition efficiencies (IE) obtained by weight loss method are given in Table 3. It was observed that when 10 ml of flower extract was added to well water, the corrosion rate decreases significantly and an inhibition efficiency of 84 % was obtained. This is due to the adsorption of active principles of May flower extract on the metal surface. As the concentration of flower extract increases, the corrosion rate decreases and the inhibition efficiency increases. (Fig. 8).

Table 3. Corrosion rates (CR) of mild steel immersed in well water (WW) in the absence and presence of May flower extract and the inhibition efficiencies (IE) obtained by weight loss method

<table>
<thead>
<tr>
<th>FE ml</th>
<th>CR mdd</th>
<th>IE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>23.45</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>12.66</td>
<td>46</td>
</tr>
<tr>
<td>4</td>
<td>10.55</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>7.97</td>
<td>66</td>
</tr>
<tr>
<td>8</td>
<td>6.10</td>
<td>74</td>
</tr>
<tr>
<td>10</td>
<td>3.75</td>
<td>84</td>
</tr>
</tbody>
</table>

Fig. 8. Correlation between concentration of May flower extract, corrosion rate and Inhibition Efficiency (IE)

4.3. Corrosion inhibition by WW+ TiO$_2$ 100 ppm + 10 ml of May FE System

Corrosion rates (CR) of mild steel immersed in well water (WW) in the absence and presence of TiO$_2$ and an aqueous extract of May flower extract (FE) and the inhibition efficiencies (IE) obtained by weight loss method are given in Table 4. It was observed that when 100 ppm of TiO$_2$ was added to well water, the corrosion rate significantly decreased, and an inhibition efficiency of 80 % was obtained. This is due to the adsorption of TiO$_2$ nanoparticles on the metal surface. When 10 ml of flower extract was added to well water, the corrosion inhibition efficiency was 84 %. When both 100 ppm of TiO$_2$ and 10 ml May flower extract were added, the IE was 95 %. Hence, one can conclude that the WW+ TiO$_2$ 100 ppm + 10 ml of FE system offers the best inhibition efficiency. TiO$_2$ is adsorbed on the metal surface and offers corrosion protection by preventing water molecules and aggressive ions from reaching the metal surface. The active principles of FE are adsorbed on the TiO$_2$ layers. These layers are hydrophobic in nature and prevent water molecules reaching the metal surface (Fig. 9).

5. Adsorption isotherm for TiO$_2$ system

The adsorption of inhibitor molecules (TiO$_2$ ppm) obeys Langmuir Adsorption Isotherm (Fig. 10). A graph was made by plotting C vs C/θ, where C is concentration of inhibitor and θ is surface coverage. A linear plot
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<table>
<thead>
<tr>
<th>System</th>
<th>CR mdd</th>
<th>IE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>23.45</td>
<td>-</td>
</tr>
<tr>
<td>WW+TiO$_2$ 100 ppm</td>
<td>4.71</td>
<td>80</td>
</tr>
<tr>
<td>WW+10ml of FE</td>
<td>3.77</td>
<td>84</td>
</tr>
<tr>
<td>WW+TiO$_2$ 100 ppm + 10ml of FE</td>
<td>1.18</td>
<td>95</td>
</tr>
</tbody>
</table>

FIG. 9. Correlation between corrosion rates and inhibition efficiencies for various systems

was obtained with $R^2$ value of 0.980. This indicated that the adsorption of molecules on the metal surface obeyed the Langmuir adsorption isotherm. The slope was 0.940 and intercept was 33.88. The Langmuir constant, K (calculated from the relation Intercept = $\log K$), was found to be $7.59 \times 10^{33}$.

FIG. 10. Langmuir adsorption isotherm for TiO$_2$ system

Since the Langmuir adsorption isotherm is obeyed, it implies that:

- The adsorption of a single adsorbate onto a series of equivalent sites on the surface of the solid.
- The surface containing the adsorbing sites is perfectly flat plane with no corrugations (assuming an homogeneous surface).
• The adsorbing molecule adsorbs into an immobile state.
• All sites are equivalent.
• Each site can hold at most one molecule of inhibitor (monolayer coverage only).
• There are no interactions between adsorbed molecules on adjacent sites.
• The formation of Langmuir monolayers by adsorption onto a surface dramatically reduces the entropy of the molecular system.

5.1. Adsorption isotherm for May flower system

The adsorption of inhibitor molecules (May flower extract in ml) obey Langmuir Adsorption Isotherm (Fig. 11). A graph was made by plotting $C$ vs $C/\theta$, where $C$ is concentration of inhibitor and $\theta$ is surface coverage. A linear plot was obtained with $R^2$ value of 0.970. This indicated that the adsorption of molecules on the metal surface obeyed the Langmuir adsorption isotherm. The slope was 0.933 and the intercept was 3.088. The Langmuir constant, $K$ (calculated from the relation Intercept = log $K$) was found to be $1225 \times 10^3$.

![Fig. 11. Langmuir adsorption isotherm for May flower system](image)

6. Potentiodynamic polarization study

Electrochemical analyses, such as Polarization study and AC impedance spectra, have been used to investigate the corrosion resistance of metals [20–25].

In the polarization study, if corrosion resistance increases, linear polarization Resistance (LPR) value increases and corrosion current decreases. In the present study, the corrosion resistance of mild steel immersed in well water in the presence and absence of an aqueous May flower extract and TiO$_2$ has been investigated by a potentiodynamic polarization study (Fig. 12). The corrosion parameters such as corrosion potential ($E_{corr}$), Tafel slopes ($b_c$ = cathodic, $b_a$ = anodic), LPR values and corrosion current ($I_{corr}$), derived from the TAFEL plots, are given in the Table 5.

When mild steel was immersed in well water (WW), the corrosion potential was $-631$ mV vs SCE, the LPR value was 7249 ohm cm$^2$ and the corrosion current was $5.268 \times 10^{-6}$ A/cm$^2$.

It is interesting to note that when mild steel was immersed in well water containing 100 ppm of TiO$_2$, the corrosion resistance of mild steel increased. This was due to the presence of TiO$_2$ nanoparticles in the medium. The nanoparticles were adsorbed onto the metal surface, forming a protective film. Hence, corrosion resistance increased. This was revealed by the fact that when the mild steel was immersed in WW containing TiO$_2$, the LPR value increased from 7249 ohm cm$^2$ to 8350 ohm cm$^2$. The corrosion current value decreased from $5.268 \times 10^{-6}$ A/cm$^2$ to $1.587 \times 10^{-6}$ A/cm$^2$.

When mild steel was immersed in WW+10 ml of FE + system, it was inferred that the corrosion resistance of mild steel increased. This was revealed by the fact that, in presence of flower extract, the LPR value was high (30994 ohm cm$^2$); the corrosion current decreased to $1.045 \times 10^{-6}$ A/cm$^2$ and the corrosion potential shifted
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The corrosion parameters of mild steel immersed in well water (WW) in the absence and presence of TiO$_2$ and an aqueous flower extract (FE), obtained by polarization study are given in Table 5. The data show that the corrosion potential ($E_{corr}$) shifted to the cathodic side (from $-631$ to $-641$ mV vs SCE) in the presence of TiO$_2$ and flower extract, indicating a protective film formation on the metal surface. The corrosion current ($I_{corr}$) decreased significantly, and the LPR ($LPR = \frac{I_{corr}}{E_{corr}}$) increased, indicating improved corrosion resistance.

**TABLE 5.** Corrosion parameters of mild steel immersed in well water (WW) in the absence and presence of TiO$_2$ and an aqueous flower extract (FE), obtained by polarization study.

<table>
<thead>
<tr>
<th>System</th>
<th>$E_{corr}$ (mV vs SCE)</th>
<th>$b_c$ (mV/decade)</th>
<th>$b_a$ (mV/decade)</th>
<th>LPR (ohm cm$^2$)</th>
<th>$I_{corr}$ (A/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>$-631$</td>
<td>202</td>
<td>155</td>
<td>7249</td>
<td>$5.268 \times 10^{-6}$</td>
</tr>
<tr>
<td>WW+TiO$_2$ 100 ppm</td>
<td>$-663$</td>
<td>221</td>
<td>120</td>
<td>8350</td>
<td>$1.587 \times 10^{-6}$</td>
</tr>
<tr>
<td>WW+10 ml of FE</td>
<td>$-670$</td>
<td>199</td>
<td>119</td>
<td>30994</td>
<td>$1.045 \times 10^{-6}$</td>
</tr>
<tr>
<td>WW+TiO$_2$ 100 ppm + 10 ml of FE</td>
<td>$-641$</td>
<td>186</td>
<td>165</td>
<td>36770</td>
<td>$1.035 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

Fig. 12. Polarization curves of mild steel immersed in various test solutions (a) WW, (b) WW+TiO$_2$ 100 ppm, (c) WW+10 ml of FE, (d) WW+TiO$_2$ 100 ppm + 10 ml of FE

To the cathodic side (from $-631$ to $-641$ mV vs SCE). This means that the cathodic reaction was controlled predominantly. The active principle present in the flower extract forms a protective film on the metal surface. The transfer of electrons from the metal to the bulk of the system was prevented. Because of the necessity of electrons, the cathodic reaction, which involves the interaction of electrons with oxygen and water, is minimized, thus, the formation of hydroxide ions is reduced.

When mild steel was immersed in the WW+10 ml of FE + TiO$_2$ 100 ppm system, the corrosion resistance of mild steel further appeared to be further increased. This is revealed by the fact that, in presence of flower extract, the LPR value was very high (36770 ohm cm$^2$); the corrosion current decreased to $1.035 \times 10^{-6}$ A/cm$^2$ and the corrosion potential shifted to the cathodic side (from $-631$ to $-670$ mV vs SCE). This means that the cathodic reaction was controlled predominantly. The active principle present in the May flower extract forms a protective film on the metal surface. The transfer of electrons from the metal to the bulk of the system was prevented. Because of the need for electrons, the cathodic reaction, which involves the interaction of electrons with oxygen and water, is limited, thus, the formation of hydroxide ions is reduced. However, when compared with the WW+10 ml of FE system, ($-670$ mV vs SCE), the shift is anodic ($-641$ mV vs SCE). This shift revealed that in presence of TiO$_2$, the anodic reaction is also controlled. Moreover, when compared with $-631$ mV vs SCE, this shift is very small. So it can be considered that the “WW+10 ml of FE + TiO$_2$ 100 ppm system” functions as a mixed inhibitor system, controlling both the anodic and cathodic reactions. Thus, the polarization study leads one to the conclusion that the corrosion resistance of mild steel in various test solutions decreases in the order:

WW+TiO$_2$ 100 ppm + 10 ml of FE system > WW+10 ml of FE > WW+TiO$_2$ 100 ppm > WW

From the data, one can conclude that the WW+TiO$_2$ 100 ppm + 10ml of FE system offers better inhibition efficiency than other systems.
AC impedance spectra have been used to investigate the corrosion resistance of metals. When corrosion resistance increases, the charge transfer resistance values ($R_t$) increase, impedance values increase and double layer capacitance values ($C_{dl}$) decrease [26–30]. AC impedance spectra of mild steel immersed in various test solution are shown in Figs. 14 – 17. Nyquist plots are shown in (Fig. 14), and Bode plots are shown in Fig. 15 – 17. The corrosion parameters are given in Table 6.

### Table 6. Corrosion parameters of mild steel immersed in well water (WW) in the absence and presence of TiO$_2$ and an aqueous May flower extract (FE), obtained by AC impedance spectra

<table>
<thead>
<tr>
<th>System</th>
<th>$R_t$ ohm cm$^2$</th>
<th>$C_{dl}$ F/cm$^2$</th>
<th>Impedance Log(z/ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>181</td>
<td>$2.78 \times 10^{-8}$</td>
<td>2.543</td>
</tr>
<tr>
<td>WW+TiO$_2$ 100 ppm</td>
<td>782</td>
<td>$0.639 \times 10^{-8}$</td>
<td>3.152</td>
</tr>
<tr>
<td>WW+10 ml of FE</td>
<td>1021</td>
<td>$0.490 \times 10^{-8}$</td>
<td>3.251</td>
</tr>
<tr>
<td>WW+TiO$_2$ 100 ppm + 10 ml of FE</td>
<td>1080</td>
<td>$0.463 \times 10^{-8}$</td>
<td>3.261</td>
</tr>
</tbody>
</table>

It was observed from Table 6 that when the inhibitor (TiO$_2$ 100 ppm) was added to well water, the charge transfer resistance ($R_t$) increased from 181 $\Omega$ cm$^2$ to 782 $\Omega$ cm$^2$. The $C_{dl}$ value decreased from $2.78 \times 10^{-8}$ F/cm$^2$ to $0.639 \times 10^{-8}$ F/cm$^2$ and the impedance value increased from 2.543 to 3.152. These results lead one to conclude that a protective film was formed on the metal surface. Nanoparticles of TiO$_2$ have adsorbed on the metal surface forming protective film. The surface becomes hydrophobic, hindering water molecules and aggressive ions from reaching the surface, thus protecting the metal from corrosion.

When the inhibitor (10 ml of may flower extract) was added to well water, the charge transfer resistance ($R_t$) increased from 181$\Omega$ cm$^2$ to 1021 $\Omega$ cm$^2$, the $C_{dl}$ value decreased from $2.78 \times 10^{-8}$ F/cm$^2$ to $0.490 \times 10^{-8}$ F/cm$^2$ and the impedance value increased from 2.543 to 3.251. These results would seem to indicate that a protective film was formed on the metal surface. This film is more compact and hydrophobic than the previous case, which is why the $R_t$ value of this system is higher than that of the previous system.

It was observed that the WW+TiO$_2$100 ppm + 10 ml of FE system is more corrosion resistant than the previous system because for this system, the $R_t$ value increases to 1080 $\Omega$ cm$^2$ and the $C_{dl}$ value decreases to $0.463 \times 10^{-8}$ F/cm$^2$ and the impedance value increases to 3.261. It seems that the flower extract and TiO$_2$ particles are adsorbed jointly on the metal surface and thus form a better protective film. Thus, AC impedance spectra lead to the conclusion that corrosion resistance of mild steel in various test solutions decreases in the following order:

*WW+TiO$_2$ 100 ppm + 10 ml of FE system > WW+10 ml of FE > WW+TiO$_2$ 100 ppm > WW.*

The WW+TiO$_2$ 100 ppm + 10 ml of FE system offers better inhibition efficiency than other systems. This view is in agreement with the polarization study results.
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**Fig. 14.** AC impedance spectra (Nyquist Plots) of mild steel immersed in various test solutions (a) WW, (b) WW+TiO$_2$ 100 ppm, (c) WW+10 ml of FE, (d) WW+TiO$_2$ 100 ppm + 10 ml of FE

**Fig. 15.** AC impedance spectrum (Bode Plot-impedance) of mild steel immersed in well water (a) WW

**Fig. 16.** AC impedance spectra (Bode Plots-impedance) of mild steel immersed in various test-solutions (b) WW+TiO$_2$ 100 ppm, (c) WW+10 ml of FE, (d) WW+TiO$_2$ 100 ppm + 10 ml of FE
FIG. 17. AC impedance spectra (Bode Plots-phase angle) of mild steel immersed in various test Solutions. black line – WW, grey line – WW+ TiO₂ 100 ppm, blue line – WW+ 10 ml of FE, red line – WW+TiO₂ 100 ppm + 10 ml of FE

7. Conclusion

The present study leads to the following conclusions:

- Titanium dioxide nanoparticles, along with an aqueous may flower extract has been synthesized successfully.
- The formulation consisting of 100 ppm of TiO₂ nanoparticles and 10 ml may flower extract afforded a 95 % IE for mild steel immersed in well water.
- Polarization study reveals that 100 ppm of TiO₂ nanoparticles and 10 ml may flower extract functions as mixed inhibitor system, controlling both anodic and cathodic reactions.
- AC impedance spectra reveal that the formation of protective film on the metal’s surface.

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References

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