Evaluation of the corrosion wear speed of different equipment in the water injection treatment plant

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Abstract. The paper presents the results of the theoretical and experimental researches carried out for the evaluation of the corrosive rate of different equipment from water injection treatment plant used for water flooding. The degradation are occurring mainly at pipelines and connecting elements of the flotation skid, in the form of advanced corrosion wear because the water injection contains an inconsistent composition mixture of dissolved gases, hydrocarbons, solid particles. The manifestation of corrosion wear at the skid connections indicates that the mechanical-physical-chemical treatments used to reduce aggressiveness are not sufficiently effective. The tests were carried out on the corrosion specimens taken from the critical areas of the skid connections and using the different formation water taken from the same critical points. Corrosion rate was obtained through experimental tests made in accordance with ASTM G5-15 and ASTM G1-03. The results materialized in the form of an influence of corrosion inhibitor and temperature on the corrosion rate for different formation water samples.

1. Introduction
Oil from reservoirs that have come to the surface through various exploitation methods contains water, gas and suspended solids. The fluid mixture coming from the wells to the park through the mixing pipes is guided through a manifold to different separators to separate the phases. Under the operating conditions in Romania, the deposit water represents on average about 60 ... 70% of the total amount of fluid extracted from the wells.

The collection consists of transporting the heterogeneous mixture of crude oil, reservoir water, associated gases and solid impurities from the production wells to treatment plants. Collecting and centrally separating well production has the advantage of requiring a smaller number of equipment’s (separators, pumps, reservoirs, etc.), which increases economic efficiency. At the same time, these facilities serve to calibrate the production of each production wells.

Formation water resulting from separation and treatment is sent to specially prepared tanks for treatment and then injected into specially prepared wells. Formation waters separated from oil and gas is used as injection water (technological water) in secondary recovery processes or to be eliminated by injection (waste water) in specially designed wells.

Regardless of the destination, injection water must meet the following qualities, [1]:
• a high degree of purity obtained thought the lowest possible mechanical and oil content;
• lower degree of aggressiveness (corrosion);
• the highest stability;
• compatibility with the fluids and minerals in the reservoir formation;
• low oxygen content and bacteria.
Factors to be taken into account when choosing an injection water treatment system are related to the distances to sources and injection points and also to the possibilities of location on the ground so that gravity can be used in the process of pumping water [2].

The treatment and injection systems (open, closed or semi-closed systems) are selected according to the characteristics of the injection water.

A complete water treatment plant (Figure 1), comprising a chemical conditioning kit, a SPINSEP dissolved gas flotation unit and a MONOSEP walnut filter.

![Figure 1. Water treatment plant design. [1]](image)

The water is taken from a tank with a pump set and sent to the chemical conditioning units. Here two chemical agents are added and conditioned to modify the water content of the particles, facilitating separation. Both the SPINSEP flotation system and the MONOSEP filter have a vertical design for a minimum surface area. Formation water is pumped from storage tanks to the treatment plant, the chemical conditioning subsystem, with three centrifugal water transfer pumps. The water is transferred through the flocculant and coagulant injection system into the secondary separation system, SPINSEP. In addition to the flocculant and coagulant, seawater is also treated with an oxygen inhibitor to remove dissolved oxygen in water and a biocide to remove bacteria.

The main degradations occurred at the equipment in the water treatment plants were recorded mainly in the pipes and the connecting elements of the SPINSEP gas flotation skid, in the form of their advanced corrosion. Locations of these degradations were founded at bends and elbows where the direction of the pipes is changed to 90° to ensure a turbulent tangential flow of the fluid at the entrance to the flotation vessel, at section changes of the pipes, to the connecting elements (flanges, threads) provided at the pipes of the gas flotation skid, welding joints.
2. Experiments tests

2.1. Corrosion tests
Experimental tests were performed in order to establish the influence of corrosion inhibitor and temperature on corrosion rate in different stages of treatment in an injection plant. Electrochemical parameters were obtained using Voltalab 10 system and Voltamaster software, tests being performed according to ASTM G5-15, [4] and ASTM G1-03(2017), [5] ed.1 standards.

2.2. Samples preparation
It is known that stress move the material electrochemical potential to became more anodic, and also fluid speed, turbulence, changing directions and sections increase corrosion wear [6,7,8] so at injection water circuit in injection plant elbows were critical zones. So, samples were extracted from extrados 6 in. elbows (P285NH - chemical composition is presented in Table 1 according to EN 10222-4 and compare with experimental test made with Oxford Foundary-Master Pro) without affecting the material structure by waterjet cutting machine. Disks with Ø 16 X 3 mm were machined by grinding at low intensive parameters using cooling fluid.

| Table 1. Chemical composition % of steel P285NH (1.0477). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| C | Si | Mn | Ni | P | S | Cr | Mo | V |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| max | max | max | max | max | max | max | max | max |
| 0.18 | 0.04 | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.02 |

The surface exposed to corrosion test medium were polished with abrasive paper of 500 Mesh gradually. In Figure 2 is presented the corrosion cell and potentiostat. Corrosion cell works with a saturated calomel reference electrode (Pt/Hg/Hg2Cl2), graphite counter electrodes and specimen holder expose 1 cm² of the specimen to the 1000cm³ test solution.

![Corrosion cell and potentiostat](a) (b)

**Figure 2.** Corrosion cell and potentiostat. (a) Corrosion cell; (b) Potentiostat.

2.3. Corrosion rate calculus
There are several electrochemical techniques that can be used to evaluate the behavior of materials in aggressive medium such as [9,10,11,12]: potentiodynamic anodic, cathodic or both polarization measurements, galvanic corrosion measurements, potentiostatic measurements, linear polarization, pitting scans, Evans plots measurements etc. Evans plots technique quickly yields corrosion rate information. The linear portion of the anodic or cathodic polarization logarithm current vs. potential plot is extrapolated to intersect the corrosion potential line (Tafel plots). This permits rapid, high accuracy measurement of extremely low corrosion rates. For this reason, to determine electrochemical
parameters we used this technique.

According to the mixed potential theory [6,7], any electrochemical reaction can be divided into two or more oxidation and reduction reactions and can be no accumulation of electrical charge during the reaction. In a corroding system, corrosion of the metal and reduction of some species in solution is taking place at same rate and the net measurable current, \( i_{\text{net}} \), is zero. Electrochemically, corrosion rate measurement is based on the determination of the oxidation current, \( i_{\text{ox}} \) at the corrosion potential, \( E_{\text{corr}} \). This oxidation current is called the corrosion current, \( i_{\text{corr}} \).

\[
i_{\text{net}} = i_{\text{ox}} - i_{\text{red}} = 0
\]

When a metal or an alloy came in contact with an aggressive medium the material potential in open circuit is the corrosion potential \( E_{\text{corr}} \). Many of modern corrosion techniques are based on theoretical of shapes of the polarization curbs Stern and Geary.

If a potential is applied on material from an external source and reaction rate is controlled, we have, [8]:

\[
i_{\text{red}} = i_{\text{n}} - \frac{\eta}{\beta_1} \quad \text{and} \quad i_{\text{n}} = i_{\text{ox}} - \frac{\eta}{\beta_2}
\]

where: \( \eta \) is overpotential, equal with the difference between the material external potential applied, \( E_{\text{apl}} \) and the corrosion potential, \( E_{\text{corr}} \);

\( \beta_1 \) and \( \beta_2 \) – constants.

By logarithm of above relations, we obtain the J. Tafel equations:

\[
\eta = -\beta_c \log \frac{i_{\text{red}}}{i_{\text{n}}}
\]

\[
\eta = -\beta_a \log \frac{i_{\text{n}}}{i_{\text{ox}}}
\]

where: \( \beta_c = 2,3\beta_1 \) and \( \beta_a = 2,3\beta_2 \) are Tafel constants, cathodic respective anodic.

Once established corrosion potential \( E_{\text{corr}} \) in volts and corrosion current density \( i_{\text{corr}} \) in \( \mu A/cm^2 \) the corrosion rate could be calculated.

According to Faraday law we have:

\[
Q = \frac{nFWQ}{M}
\]

where: \( Q \) – charge, Coulomb;

\( n \) – number of electrons involved in electrochemical reactions;

\( F \) – Faraday constant, 96487 Coulomb;

\( W \) – weight loss of the material, g;

\( M \) – atomic mass of the material, g.

We could obtain corrosion rate, usually expressed in length units/time (mm/year), \( CR \):

\[
CR = i_{\text{corr}} \left( E.W. / \rho F \right)
\]

where: \( E.W. = M/n \) – equivalent weight, g;

\( n \) – number of electrons involved in electrochemical reactions;

\( \rho \) – density of the material in g/cm\(^3\).

2.4. Test mediums

Test fluids were injection waters collected in different stages of treatment at injection plant. In Table 2 are presented the injection water composition collected from outlet header of collecting park which are transferred to injection plant.
Table 2. Injection water at outlet collecting park header composition.

| Element     | Free CO₂ | Dissolved CO₂ | Sulfurs | Barium | Calcium | Dissolved Fe | Total Fe | Potassium mg/l |
|-------------|----------|---------------|---------|--------|---------|--------------|----------|----------------|
| Value, mg/l | 88       | 28            | 0.04    | 103    | 3573    | 34           | 35       | 170            |

| Element     | Magnesium | Natrium | Strontium | Bromides | Chlorides | Iodides | Bicarbonates | Lithium mg/l |
|-------------|------------|---------|-----------|----------|-----------|---------|--------------|---------------|
| Value, mg/l | 1779       | 17550   | 127       | 143      | 39440     | 13      | 195          | 2.4           |

The injection water from collecting park enter in the injection treatment plant and was labelled as Sample 1. The water samples were labelled according to the collecting point at different stages in the injection treatment plant as presented in Table 3. The pH of water samples was established with pH-meter type Radiometer PHM - 201 Bc with combined pH electrode and an electrode for temperature.

Table 3. Injection waters samples.

| Labelling | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 5 |
|-----------|----------|----------|----------|----------|----------|----------|
| Collecting stages position | Outlet collecting park | Decantation tank outlet | Buster pump inlet | SPINSEP inlet | SPINSEP outlet | Outlet from plant |
| pH value at 25°C | 6.46 | 6.78 | 6.88 | 6.94 | 6.98 | 7.06 |

In order to evaluate the temperature and corrosion inhibitor influence on corrosion rate were performed tests at 25°C, 30°C and 35°C and at different corrosion inhibitor concentrations. The corrosion inhibitor must be correlated with material and medium. Was used a corrosion inhibitor type CRW 85579 which contains etandiol, ethers, dodecenylsuccinic acid, quaternary ammonium compounds, benzyl (hydrogenated tallow alkyl), dimethyl and chlorides. Tests were performed at 0ppm, 30ppm, 60ppm, 100ppm and 480ppm.

3. Results

3.1. Corrosion test

In Figure 3 it is shown the Voltamaster capture with Evans plots for tested elbow sample material (P285NH) in Sample 3 injection water. The plots (fig. 3 and 4) were obtained from the Voltamaster software, applying the relation presented in paragraph 2.3, based on the increase rate of corrosion potential with an 1 mV/sec and the corrosion current witch occurs.

Electrochemical parameters obtained for extrados elbow material samples tested in injection water samples at 25°C are presented in Table 4.

The Voltamaster software can calculates the following input and output parameters:

- Input
  - Calomel reference electrode (the potential measured according to used electrode);
  - Sample exposed to medium surface, 1 cm²;
  - Material sample, P285NH (iron element witch is corroded – Fe with atomic mass of 55.85 g, valence of 2 and density 7.85 g/cm³);
  - Analyses potential domain – 1000 mV to + 1000 mV;
  - Smoothing, calcul zone and segment were choosed in order to obtain for multiple determination coefficient, Coef=1.
- Output
- $E(i=0)$ – corrosion potential, mV;
- $R_p$ – polarization resistance, ohm.cm²;
- $i_{corr}$ – corrosion current density, μA/cm²;
- $B_c, B_a$ – Tafel constants, cathodic respective anodic;
- $Coef$ – multiple determination coefficient;
- $Corrosion$ - corrosion rate, mm/year.

### Table 4. Electrochemical parameters for extrados elbow material in injection water samples.

| Water samples | Electrochemical parameters |
|---------------|---------------------------|
|               | Current density, μA/cm² | Corrosion potential, mV | Corrosion rate, mm/year |
| Sample 1      | 57.0656                   | -693.2                    | 0.6632                  |
| Sample 2      | 50.8816                   | -565.0                    | 0.5913                  |
| Sample 3      | 50.8673                   | -641.7                    | 0.5911                  |
| Sample 4      | 44.6664                   | -661.8                    | 0.5191                  |
| Sample 5      | 41.8391                   | -687.2                    | 0.4862                  |
| Sample 6      | 37.7738                   | -667.2                    | 0.4389                  |

### Figure 3. Electrochemical parameters and Evans plots for Sample 3 injection water at 25°C.

Analyzing the results showed in table 4 we could conclude that the corrosion rate obtained have important values even in treatment injection water plant these values are diminished the final water which will be injected in wells has still a great value.

Formation water composition presented in table 1, show that it is aggressive but decantation, corrosion inhibitor used, and filtration must conduct to smaller values of corrosion rate. This higher water aggressivity produce erosion-corrosion wear at elbows which have a durability of 6 month.

Increasing the temperature, the electrochemical reactions are accelerated, and corrosion rate became greater. In Figure 4 it is shown the electrochemical parameters and Evans plot at 30°C.

Electrochemical parameters obtained at 25°C, 30°C and 35°C are presented in Table 5. This testing temperatures for injection waters are usually obtained in spring and summer.
Figure 4. Electrochemical parameters and Evans plots for Sample 3 injection water at 30°C.

The corrosion inhibitor optimum dilution is very important to inhibitor effectiveness. The corrosion rate values presented in table 5 suggest that inhibitor concentration was not proper used in correlation with injection water composition and temperature.

Table 5. Electrochemical parameters for extrados elbow material in injection water sample 3 at different temperatures.

| Water sample 3 temperature, °C | Electrochemical parameters | Corrosion potential, mV | Corrosion rate, mm/year |
|-------------------------------|-----------------------------|--------------------------|-------------------------|
| 25                            | 50.8673                     | -641.7                   | 0.5911                  |
| 30                            | 58.2614                     | -701.7                   | 0.6771                  |
| 35                            | 72.4090                     | -656.5                   | 0.8415                  |

From table 5 we observe an important increase of corrosion rate with temperature which confirm the small elbow durability.

In Table 6 are shown the results of electrochemical parameters obtained for different corrosion inhibitor type CRW 85579 concentrations.

Table 6. Electrochemical parameters for extrados elbow material in injection water with different CRW corrosion inhibitor concentration.

| Corrosion inhibitor concentration in injection water, ppm | Electrochemical parameters | Corrosion potential, mV | Corrosion rate, mm/year |
|----------------------------------------------------------|-----------------------------|--------------------------|-------------------------|
| 0                                                        | 57.0656                     | -693.2                   | 0.6632                  |
| 30                                                       | 24.8311                     | -625.6                   | 0.2885                  |
| 60                                                       | 6.5744                      | -669.2                   | 0.0764                  |
| 100                                                      | 36.9839                     | -654.1                   | 0.4298                  |
| 480                                                      | 54.5723                     | -634.9                   | 0.6342                  |
We observe from values presented in table 6 that optimum corrosion inhibitor concentration is 60 ppm (0.06 ml/l). With the increase of corrosion inhibitor concentration, the corrosion rate is greater. The corrosion rate obtained at CRW 480 ppm in injection water suggest that at injection plant were used such values of CRW concentration. The optimum CRW concentration obtained is for formation water composition presented in table 2 and at 25°C. At different temperatures and compositions of waters the optimum value will be different.

4. Conclusions

Experimental program carried out in this paper consisted of the corrosion test on specimens (Ø 16 X 3 mm disks) extracted from elbows used in pipes water circuit in injection plant in 6 water samples, taken from water injection treatment plant, labelled Sample 1 … Sample 6 (Outlet collecting park, SPINSEP inlet, SPINSEP outlet, Outlet from plant), in order to establish the injection waters aggressiveness in different stages of treatment in the plant and to obtain the optimum corrosion inhibitor concentration.

Experimental analysis of pH values for all 6 formation water samples leads to the conclusion that water samples have a slightly acidic character reaching neutral pH at water outlet from injection treatment plant (Sample 6 pH = 7.06).

Corrosion tests carried out at 25°C, 30°C and 35°C on specimens extracted from an elbow lead to the general conclusion that the corrosion rate is high, decreasing from the water inlet to outlet of the treatment plant. The corrosion rate increases significant with the temperature. We notice that in summer the water temperature easily reaches 30°C or 35°C.

The concentration of corrosion inhibitors introduced into the formation water is very important, the optimal value of corrosion rate (60 ppm at 25°C) is obtained. An important observation is that with increasing concentration of inhibitors, from a certain value of this concentration, an increase in the corrosion rate is obtained.

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