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Computer Aided Evaluation and Assessment of Aggressiveness or Tendency of Water to Form Alkaline and Sulfate Scales

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ABSTRACT

Our study introduces an interactive software tool developed in Visual Basic for predicting and evaluating the formation of hard scales in water during various operational conditions. Water properties such as pH, alkalinity, CO_2 gas pressure, ionic strength, and operating temperature and pressure are required inputs for the software. It provides efficient data storage, water analysis capabilities, and output formatting. Users can input water analysis results and operating conditions using different units, generating multiple interpretable outcomes, including Langelier Saturation Index (LSI), Ryznar Saturation Index (RSI), Calcium Carbonate Precipitation Potential (CCPP), Stiff and Davis Stability Index (SDI), and Oddo and Tomson Index (OTI). Furthermore, the software predicts the dissolution rates of concrete in aggressive water for pre-stressed concrete cylinder pipes (PCCP). Real-time data from various sources, including the Great Man River Project (GMRP), Arabian Gulf Oil Company, Melita Oil and Gas Company, and Zueitina Oil Company, validate the software's accuracy and reliability. This software enhances water property management, improves operational efficiency, and lowers maintenance costs.

1. INTRODUCTION

Water is an essential resource for various industrial processes, serving critical roles in cooling, heating, and transportation. However, the properties of water can present challenges that impact operational efficiency and productivity. One such challenge is the formation of scales and corrosion in industrial water systems [1].

Scale formation occurs when dissolved minerals in water precipitate and adhere to surfaces, resulting in the formation of hard deposits. Over time, these deposits can accumulate and cause pipe blockages, reduced heat transfer efficiency, and restricted fluid flow. As a result, scale formation hampers the performance and longevity of industrial systems, leading to production losses and increased maintenance costs [2-4].

Corrosion, on the other hand, involves the electrochemical deterioration of metal surfaces in contact with water. Corrosive reactions can weaken infrastructure, impair equipment functionality, and compromise safety. When scale formation and corrosion occur simultaneously, their detrimental effects intensify, presenting even greater challenges in maintaining the integrity and efficiency of industrial water systems [5, 6].

The issues of corrosion and scale formation are complex and costly for industries that rely on water for their processes. These problems can result in equipment failure, reduced operational efficiency, increased maintenance costs, and potential safety hazards [7, 8]. Therefore, it is crucial for industries to implement effective mitigation strategies to prevent or minimize the detrimental effects of corrosion and scale formation in their water systems.

This paper aims to provide a comprehensive understanding of the challenges posed by corrosion and scale formation in industrial water systems. Through two specific case studies, namely the Tazerbo and Jufra fields for the Great Man-Made River Project and oil companies in the Libyan desert, we will explore the underlying mechanisms, consequences, and mitigation strategies associated with these challenges.

The Tazerbo fields, which are designed to convey 1.68 million cubic meters of water per day [9], also face challenges related to mineral scales. Located in the Libyan Desert, these fields encounter aggressive water containing dissolved carbon dioxide (CO_2). The presence of CO_2 in water leads to the formation of carbonic acid (H_2CO_3), which is highly corrosive to concrete linings, collectors, and main conveyance pipelines [10]. To mitigate the aggressive nature of the water, the installation of degassers at the well heads using an air stripping method to remove free CO_2 was considered.

Table 1. Cost comparison of carbon dioxide removal alternatives

No.	Scheme Degassing	Cost US$ (Thousands) (April 92)
1	Tower	63,667
2	Twinned Degassers	69,370
3	Central Degassers	123,479

The selection of the appropriate degassing method is influenced by various factors, including cost. A cost comparison of three degassing schemes for the Tazerbo field is presented in Table 1.

Based on the cost comparison, Scheme 1, which involves installing a degassing tower on each well head, was found to be the most economical and technically feasible option. This alternative requires the least initial capital investment and ensures degassing performance through a specialist supplier [11].

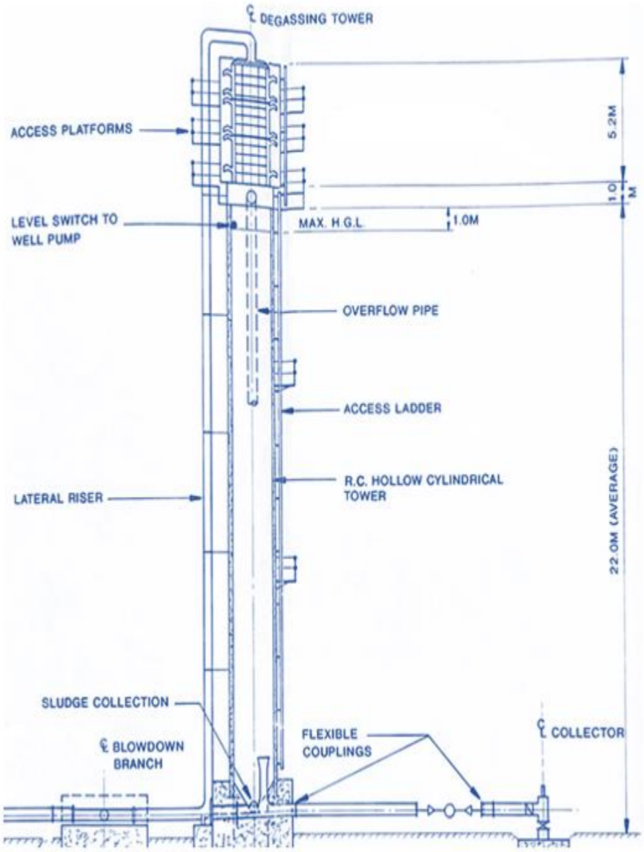

Figure 1. Scheme 1 degassing tower

Figure 1 illustrates Scheme 1, where water is pumped to the top of the degassing tower through the riser. After degassing, the water is fed into the tower through the fall of water by gravity, creating a head pressure. Each well is equipped with a degasser tower, built at a height above ground level for efficient degassing.

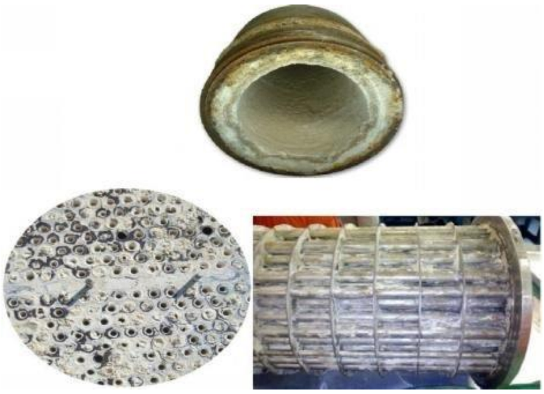

Figure 2. Display precipitated salts on heat transfer surfaces [12]

Calcium carbonate, calcium sulfate, and silica are the most common minerals that form scales and can deposit on heat transfer surfaces, pipes, and equipment, reducing their efficiency and causing operational issues. To control scale formation, various methods are available. Chemical treatment with scale inhibitors and descaling processes using acid-based solutions or mechanical methods are commonly employed [13]. Figure 2 displays the precipitated salts on heat transfer surfaces, highlighting the detrimental effects of scale formation.

Understanding the mechanisms of scale formation is essential for implementing effective control strategies.

Figure 3 provides an overview of how scaling occurs on surfaces, influenced by factors such as water composition, pH, temperature, and pressure.

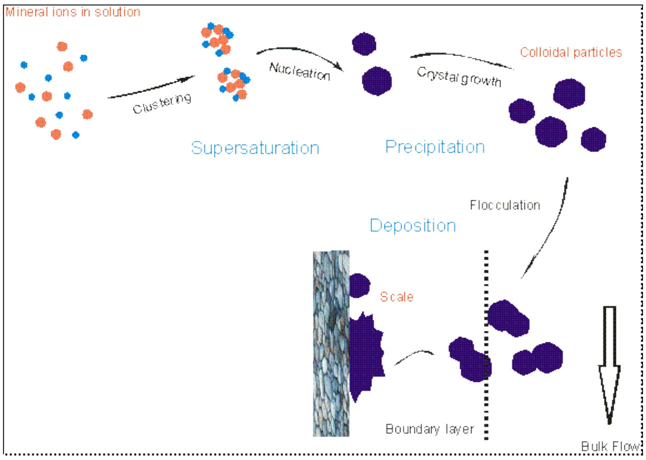

Figure 3. Overview of scaling formation on surfaces [14]

In addition to the direct losses associated with corrosion, such as the replacement of corroded structures, there are several indirect losses. Leaking storage tanks and water or oil transportation lines can cause significant product losses and even lead to accidents. Corrosion can also reduce heat transfer efficiency by insulating heat exchanger tubes and shorten equipment life, necessitating premature replacement. Figure 4 showcases corrosion in the tube and shell of a heat exchanger.

Figure 4. Corrosion in tube and shell of heat exchanger

To address these concerns, this study introduces an innovative software tool developed in Visual Basic. The software aims to predict and assess the aggressiveness or tendency of water to form scales in diverse operating conditions. By inputting key water properties, such as pH, alkalinity, CO_2 gas pressure, ionic strength, and operating temperature and pressure, users can gain valuable insights into the scale formation risks associated with their specific industrial processes.

The software incorporates advanced algorithms and models that consider various factors contributing to scale formation. It offers efficient data storage, enabling users to store and retrieve water analysis results for further analysis. Additionally, the software provides comprehensive water analysis capabilities, allowing users to assess the concentration of scale-forming ions in the water. The output formatting options facilitate the generation of reports and visual representations of the analysis results, enhancing the usability and interpretability of the software.

By utilizing the software, users can generate multiple interpretable outcomes that assist in evaluating the scale-forming potential of water. For instance, the Langelier Saturation Index (LSI) indicates the propensity of water to form scale when the index value is positive. The software also calculates the Calcium Carbonate Precipitation Potential (CCPP), providing insights into the likelihood of calcium carbonate precipitation. Additionally, the software incorporates other indices that aid in assessing the scale formation risks.

To validate the software's accuracy and reliability, real-time data from operating oil companies were utilized. The results obtained from these data confirm the software's efficacy in accurately predicting and assessing scale formation risks, thereby enhancing its practical relevance and applicability.

In conclusion, this software tool represents a significant advancement in managing water properties and mitigating scale formation in industrial water systems. By providing valuable insights and predictive capabilities, the software enhances operational efficiency, reduces maintenance costs, and improves the overall performance and durability of industrial water systems.

2. METHODOLOGY

2.1 Saturation indexes models for predicting scaling

The five specific saturation indices mentioned in the methodology section were chosen for analysis based on their widespread use and relevance in predicting scaling potential in industrial water systems. Each index has its own limitations and suitability, which are briefly described below:

(1) Langelier Saturation Index (LSI): The LSI takes into account several factors, including temperature, pressure, specific gravity, pH, sodium, calcium, magnesium, potassium, bicarbonate, chloride, sulfate, and nitrate concentrations. It evaluates the scaling potential based on these parameters [15, 16].

(2) Ryznar Saturation Index (RSI): Similar to the LSI, the RSI considers temperature, pressure, specific gravity, pH, sodium, calcium, magnesium, potassium, bicarbonate, chloride, sulfate, and nitrate concentrations to estimate the scaling potential [17].

(3) Calcium Carbonate Precipitation Potential (CCPP): The CCPP index focuses specifically on the precipitation of calcium carbonate. It takes into account temperature, pressure, specific gravity, pH, calcium, alkalinity, bicarbonate, chloride, sulfate, and nitrate concentrations to evaluate the potential for calcium carbonate scale formation [18].

(4) Stiff and Davis Stability Index (SDI): The SDI primarily assesses the stability of water in water treatment processes, rather than scaling potential. It does not require the full set of input data mentioned, but it may consider parameters such as temperature, pH, calcium, total alkalinity and total dissolved salts [19].

(5) Oddo and Tomson Index (OTI): The OTI predicts scaling potential by considering various parameters, including temperature, pressure, specific gravity, pH, sodium, calcium, magnesium, potassium, barium, iron, strontium, bicarbonate, chloride, sulfate, and nitrate concentrations [20, 21].

The saturation index method is used to calculate various scaling indices like LSI, RSI, CCPP, and SDI. The valid ranges for these indices are:

·pH: 5 to 9.5
·Temperature: 0 to 90℃
·Total Dissolved Solids (TDS): ≤10,000 mg/L, except for SDI which can be >10,000 mg/L

The Oddo Thomson index (OTI) is used to account for the impact of pressure and partial pressure of CO_2 on water pH. The valid ranges for OTI are:

·Temperature: 0-200℃
·pH: 5-9.5
·TDS: >10,000 mg/L
·Pressure: 1-1380 bar

Carefully considering the input data and limitations of each index is crucial for accurate scaling prediction in industrial water systems.

2.1.1 Langelier Saturation Index (LSI)

The Langelier Saturation Index (LSI) is a widely used method for predicting the scaling potential of water. The Langelier Saturation Index is calculated using the equation:

$$LSI = pH - pH_s \tag{1}$$

where, pH is measured pH of the water range of 6.5 to 9.5; pH_s is the pH saturated with calcium carbonate.

pH represents the measured pH of the water sample, and pH_s is the saturation pH, which is determined based on the temperature, alkalinity, calcium, and Total Dissolved Solids (TDS) of the water.

$$pHs = (pK_{a2}' - pK_{sp}') + pCa + pAlk \tag{2}$$

As shown below, equilibrium constants at various temperatures based on water tests [22].

$$pK_i' = A + BT + C/T + Dlog_{10}T + E/T^2 + 2.3log_{10}(\gamma \pm) \tag{3}$$

where, pCa is the negative log_{10} of calcium measured (mol/L) in the water; $pAlk$ is the negative log_{10} of the total alkalinity measured (mol/L) in the water; pK_{sp}' is the negative log_{10} of the solubility product constant for C_aCO_3; pK_{a2}' is the negative log_{10} of the second dissociation constant for carbonic acid; $\gamma\pm$ is activity coefficient.

The activity coefficient ($\gamma\pm$) is used in thermodynamics to account for the non-ideal behavior of water when calculating saturation indices and chemical equilibrium constants. If the activity coefficient is less than 1, it indicates strong molecular attraction, which is essential for accurate equilibrium calculations [23].

Table 2 provides different activity models, each with a specific range defined by the ionic strength (I).

To calculate the values of I, A and B in Table 2. The following expressions can be used:

$$\mathrm{I}\left(\frac{\mathrm{mol}}{\mathrm{L}}\right) = \sum_{\text{all ions}} \mathrm{Z}^2\,\mathrm{C_i}$$
$$A = 2.74 \times 10^{-6} \times T^2 - 7.60 \times 10^{-4} \times T + 0.4916$$
$$B = 1.62 \times 10^{-4} \times T + 0.2799$$

Here are the definitions for the additional variables:

C_i: Concentration of ionic species (mol/L);
T: Temperature (in Kelvin);
I: Ionic strength (mol/L);
$Z\ \pm$: Charge of the ion;
$\mathrm{a\&b}, \mathrm{a}^0$: Constants in experiments;
A, B: Empirical parameters that depend on temperature.

In this study, the Langelier Saturation Index (LSI) is used to assess the scaling potential of water. The LSI value is calculated using equations that consider pH, water alkalinity, calcium concentration, and other relevant factors. Positive LSI values indicate a tendency for the water to form scale, while negative values suggest a corrosive nature, leading to the dissolution of scale. Table 3 provides a detailed breakdown of the LSI values and the corresponding water tendency for scaling or corrosion.

Similarly, other methods employed in this study follow a comparable process for assessing water quality. Each method utilizes specific parameters relevant to scale formation or corrosion, allowing for a comprehensive evaluation of the water's behavior in industrial applications.

Table 2. Activity models [23]

Model	Equitation	Validity
Debye-Hückel	$Log\ \gamma\pm = -AZ_{\pm}^{2}\sqrt{I}$	I<$10^{-2.3}$ M
Extended Debye-Hückel	$Log\ \gamma\pm = -AZ_{\pm}^{2}\left(\frac{\sqrt{I}}{1+Ba\sqrt{I}}\right)$	I<0.1 M
Davies	$Log\ \gamma\pm = -AZ_{\pm}^{2}\left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.3I\right)$	I≤0.5 M
Truesdell-Jones	$Log\ \gamma\pm = -AZ_{\pm}^{2}\left(\frac{\sqrt{I}}{1+Ba^{0}\sqrt{I}} + b.I\right)$	I<1 M

Table 3. Scale indicator for each LSI value for water tendency [24]

LSI	Tendency of Water
≥3.0+	Severe scale formation
2.0 - 2.9	Very strong scale formation
1.0 - 1.9	Strong scale formation
0.5 - 0.9	Moderate scale formation
0.2 - 0.4	Slight scale formation
0.1 to - 0.1	Stable water, no tendency to form or dissolve scale
- 0.2 to - 0.4	No scaling, slight tendency to dissolve scale
-0.5 to - 0.9	No scaling, moderate tendency to dissolve scale (corrosive – aggressive)
-1.0 to - 1.9	No scaling, strong tendency to dissolve scale (corrosive – aggressive)
-2.0 to - 2.9	No scaling, very strong tendency to dissolve scale (corrosive – aggressive)
-3.0 or ≺	No scaling, severe tendency to dissolve scale (corrosive – aggressive)

Table 4. Equilibrium constants of pK'_{a2} and pK'_{sp} are calculated using laboratory tests at various temperatures of water

Equations	A	B	C	D	E	Temperature Range (K^0)
pK'_{a2}	107.8871	0.03252849	-5151.79	-3892561	563713.9	273-373
pK'_{sp}	171.9065	0.077993	-2839.3192	-71.595	...	273-363

Table 5. Scale indicator for each RSI value [25]

RSI	Tendency of Water
4.0 – 5.0	Heavy scale
5.0 – 6.0	Light scale
6.0 – 7.0	Very small amount of scale/corrosion
7.0 – 7.5	No scaling, slight tendency to dissolve scale (corrosion – aggressive)
7.5 – 8.5	No scaling, moderate tendency to dissolve scale (corrosion – aggressive)
8.5 and higher	No scaling, very strong tendency to dissolve scale (corrosion – aggressive)

2.1.2 Ryznar Saturation Index (RSI)

The Ryznar Saturation Index (RSI) is a formula used to assess the water's tendency to cause scale formation or corrosion. The formula is as follows:

$$RSI = 2(pH_S) - pH \tag{4}$$

Similar to *LSI*, *pH* represents the measured *pH* of the water sample, and pH_s is the saturation *pH*, which is determined based on the water temperature, alkalinity, calcium, and TDS. pH_s calculation has been simplified to:

$$pH_S = \left(pK'_{a2} - pK'_{sp}\right) - log_{10}(Ca^{+2}) - log_{10}(Alk) + 9.30 + \frac{2.5\sqrt{I}}{1+5.3\sqrt{I}+5.5I} \tag{5}$$

where, pH is measured pH of the water; pH_S is the pH saturated with calcium carbonate; I is Ionic strength (mol/L); Ca^{+2} is calcium concentration (mg/L) in the water; *Alk* is total alkalinity concentration (mg/L) in the water; pK'_{sp} is solubility product constant for C_aCO_3; pK'_{a2} is second dissociation constant for carbonic acid, as shown in Table 4. The tendency of water to scale or corrosion was indicated by the Ryznar Stability Index as shown in Table 5.

2.1.3 Calcium Carbonate Precipitation Potential (CCPP)

Calcium Carbonate Precipitation Potential (CCPP) is considered one of the most difficult ways to estimate water saturation indices because it uses computer software to calculate the probability of calcium carbonate precipitation in water. CCPP is a more reliable indicator of water stability and, therefore, is considered a more accurate way of assessing water behavior. CCPP is determined by calculating the Calcium Carbonate Saturation Ratio (CCSR) and comparing it to a threshold value. The index is written:

$$CCPP = 50000 \times (ALK_i - ALKeq) \quad (6)$$

where, *CCPP* is in mg/L as C_aCO_3; ALK_i is initial total alkalinity concentration (eq/L) in the water; $ALKeq$ is calculated using a set of computational equations based on establishing chemical equilibrium for waters that use an iterative process to reach equilibrium, as shown by equations below:

$$2(Ca_i^{+2}) - ALKi = \frac{2k'_{sp}r_{eq}}{(Alk_{eq}+s_{eq})-Alk_{eq}} \quad (7)$$

$$Alk_{eq} = \left(\frac{t_{eq}}{p_{eq}}\right)\left(Acy_{eq} - s_{eq}\right) - s_{eq} \quad (8)$$

$$r_{eq} = \frac{H_{eq}^{+}+2k'_{a2}}{k'_{a2}}; s_{eq} = H_{eq}^{+} - \frac{k'_w}{H_{eq}^{+}} \quad (9)$$

$$p_{eq} = \frac{2H_{eq}^{+}+k'_{a1}}{k'_{a1}}; t_{eq} = \frac{2k'_2+H_{eq}^{+}}{H_{eq}^{+}} \quad (10)$$

$$Acy_{eq} = (\frac{ALK_{eq}+s_{eq}}{t_{eq}})p_{eq} + s_{eq} \quad (11)$$

where, Ca_i^{+2} is initial calcium concentration (mol/L) in the water; pk'_{a1} is first dissociation constant for carbonic acid; pk'_{a2} is second dissociation constant for carbonic acid; pk'_w is dissociation constant for water; pk'_{sp} is solubility product constant for calcite. As shown in Tables 6 and 7, equilibrium constants derived from experiments at various temperatures [22].

Table 6. pk'_{a1}, pk'_{a2}, pk'_{sp} and pk'_w in water calculated from experiment results at different temperature

Equations	**A**	**B**	**C**	**D**	**E**	**Temperature Range** (K^0)
pk'_{a1}	356.3094	0.06091964	-21834.37	-126.8339	1684915	273 - 373
pk'_{a2}	107.8871	0.03252849	-5151.79	-3892561	563713.9	273 - 373
pk'_{sp}	171.9065	0.077993	-2839.3192	-71.595	...	273 - 363
pk'_w	-6.0875	0.01706	4471	...	...	273 - 333

Table 7. Based on the calculation of Calcium Carbonate Precipitation Potential (CCPP) indices

CCPP Index (mg/L as $CaCO_3$)	**Tendency of Water**
> +20	Severely scale forming
+20 to +10	Scale forming
+10 to +5	Slightly scale forming
+5 to 0	Neither scale forming nor aggressive
0 to -5	No scaling, very slight tendency to dissolve scale
-5 to -10	No scaling, slight tendency to dissolve scale
-10 to -20	No scaling, moderate tendency to dissolve scale
<-20	No scaling, very strong tendency to dissolve scale

Predicted water aggression and assessment of the time to destroy the inner concrete core of conveyance pipeline.

The expected life span of an inner concrete core in the case of aggressive water is resulting in a reduced design life of the pipes, loss of water, and economic losses during operation. Consequently, the importance of water treatment includes measures such as con- structing degassing towers to remove gases from water producing wells, as occurred in Phase (2) of the Great Man-Made River project in 1996, before pumping water into the pipes [26].

Evaluation of the dissolution rate in relation to concrete attack

$$k = \frac{(CL - C0)\cdot D\cdot V}{(Cs - C0)(Cs - CL)\cdot 4\cdot \sigma \cdot L} \quad (12)$$

Evaluation loss on inner concrete core

$$Loss\ concrete\ (\text{Kg}) = \frac{(CL-C0)\times 365\times Years}{\sigma} \quad (13)$$

$$Loss\ of\ wall\ (thickness\ (mm)) = \frac{Loss\ of\ concrete\ \times 10^3}{\rho \cdot \Pi \cdot D \cdot L} \quad (14)$$

If there is no C_L value, the following formula can be used to calculate it:

$$CL = Cs - \frac{1}{\frac{4\cdot k\cdot \sigma \cdot L}{D\cdot V} - \frac{1}{(C0 - Cs)}} \quad (15)$$

In the calculations, the following base conditions have been assumed: *K* is dissolution rate of attack on inner concrete core in $m^4/kg.s$; C_L is calcium concentration at the outlet of the pipe in Kg/m^3; C_0 is calcium concentration at the inlet of the pipe in Kg/m^3; C_s is calcium concentration between the inlet and outlet of the pipe in Kg/m^3; CCPP Calcium Carbonate Precipitation Potential index in mg/L as C_aCO_3; *D* is diameter of the pipe in meters; *V* is flow velocity in m/s; *L* is length of pipe in meters; ρ is density of concrete in Kg/m^3; σ is fraction on concrete; Years is life span of an inner concrete core (C_s=C_0+(($CCPP$)$\frac{-1}{1000\times 2.5}$)).

2.1.4 Stiff and Davis Index (SDI)

The Stiff-Davis Index has solved the shortcomings of the Langelier index in terms of low total dissolve solid by becoming a high total dissolve solid (TDS >10,000 mg/L).

The following relationship is used to calculate the concentration *C* of each ion in mole per liter from water analysis.

$$C_i(\text{Mol/L}) = \frac{C_i(\text{Meq/L})}{Z(1000 * S_P G_r - \frac{TDS}{1000})} \quad (16)$$

where, C_i (meq/L) is ion concentration; *Z* is ion valence; *SpGr* is specific gravity of the brine; *TDS* is Total Dissolved Solids in mg/L.

The ionic strength (I) can be calculated using these molarities:

$$I=1/2(C_1Z_1^2+C_2Z_2^2+.......C_nZ_n^2) \tag{17}$$

The Stiff-Davis index can be calculated using the following equation:

$$SDI = pH - pCa - pAlk - K \tag{18}$$

A positive SDI indicates scale formation.

A negative SDI indicates an unlikely scale formation. To calculate parameters, use the equations below:

$$pCa = log\frac{1}{\text{Ca (mole/liter)}} \tag{19}$$

$$pAlk = log\frac{1}{\text{Alkalinity (equivalent/liter)}} \tag{20}$$

where, *K* is the solubility product constant, which is dependent on ionic strength and temperature, as shown in Table 8.

Table 8. K values at difference of temperature and ionic strength

Equations	Ionic Strength (mol/L)	Temperature Range (K^0)	Formula
K	If I < 1.2	0 - 363.15	$k = 2.02^{\frac{(\boldsymbol{ln(I)+7.544})^2}{2.022} - 0.0002T^2 + 0.00097T + 0.262}$
	If I > 1.2		$K=0.1I-0.0002T^2-0.00097T+3.887$

2.1.5 Oddo and Tomson Index (OTI)

The Oddo-Tomson index is more accurate than previous indicators because it uses pressure to predict calcium carbonate, calcium sulfate, barite, and celestite. Besides that, the method does not require a pH measurement; rather, the pH is calculated using the concentration of carbon dioxide gas and bicarbonate inside water due to the fact that pH measurements lose accuracy rapidly after a sample is separated from natural surroundings.

The saturation index (SI) for different scale types

The following are the most common scales formations found in industries:

$CaCO_3$ - calcium carbonate (calcite);
$CaSO_4$ - calcium sulfate, usually in the form of gypsum;
$BaSO_4$ - barium sulfate (barite);
$SrSO_4$ - strontium sulfate (celesite).

This method is applicable to the following ranges:

Temperatures range from 0 to 200℃ (32 - 392 ºF);
Pressures range from 1 to 1380 bar (0 - 20000 psi);
TDS (Total Dissolved Solids) > 10,000.

Calcite saturation index

Calculate calcite Saturation Index (SI) and pH using the equation below.

When there is a presence of *pH*.

$$\begin{aligned} SIcaco_3 &= \log\left(\left(Ca^{+2}\right)\left(HCO_3^-\right)\right) + pH - 2.76 + 9.88\times10^{-3}T \\ &+0.61\times10^{-6}T^2 - 3.03\times10^{-5}P - 2.348\times I^{1/2} + 0.77\times I \end{aligned} \tag{21}$$

When there is an absence of *pH*.

$$\begin{aligned} \log\left(C_{aq}^{CO_2}\right) &= \log\left(pCo_2\right) - 2.212 - 6.51\times103T \\ &+10.19\times10^{-6}T^2 - 1.290\times10^{-5}P - 0.077\times I^{1/2} - 0.059\times I \end{aligned} \tag{22}$$

$$\begin{aligned} pH &= \left(\left(\mathrm{HCO_3^-}\right)/\left(C_{aq}^{CO_2}\right)\right) + 6.39 - 1.198\times10^{-3}\mathrm{T} \\ &+7.94\times10^{-6}T^2 - 3.53\times10^{5}\mathrm{P} - 1.067\times I^{1/2} + 0.599\times I \end{aligned} \tag{23}$$

$$\begin{aligned} SIcaco_3 &= \left(\frac{(ca^{+2})\ (HCo_3{}^-)^2}{C_{aq}^{co_2}}\right) + 3.63 + 8.68\times10^{-3}T \\ &+8.55\times10^{-6}T^2 - 6.56\times10^{-5}P - 3.42\times I^{1/2} + 1.373\times I \end{aligned} \tag{24}$$

where, Ca^{+2} is calcium concentration (mol/L); HCO_3^- is bicarbonate (mol/L); $C_{aq}^{co_2}$ is aqueous concentration of CO_2; T is temperature (F^0); P is absolute Pressure (Psi); I is ionic strength (mol/L).

Sulfate saturation index

The following steps need to be taken to calculate sulfate anion (SO_4^-) with cation (Ca^{+2}, Ba^{+2}, Sr^{+2}).

(1) The mass-balance

The mass-balance equations for calcium, magnesium, strontium, barium, and sulfate ions are state below:

$$\begin{aligned} [Mg^{+2}] &= \frac{C_{Mg^{+2}}}{(1 + K_{st}\ .CSO_4^{-2})} \\ [Ca^{+2}] &= \frac{C_{ca^{+2}}}{(1 + K_{st}\ .CSO_4^{-2})} \end{aligned} \tag{25}$$

$$\begin{aligned} [Sr^{+2}] &= \frac{C_{Sr^{+2}}}{(1 + K_{st}\ .CSO_4^{-2})} \\ [Ba^{+2}] &= \frac{C_{Ba^{+2}}}{(1 + K_{st}\ .CSO_4^{-2})} \end{aligned} \tag{26}$$

$$[\mathrm{SO_4^{-2}}] = \frac{\{\{-[1+K_{st}(C_m - C_{SO_4^-2}\ )] + [1+K_{st}(C_m - C_{SO_4^-2})]^2 + 4K_{st}C_{so_4^-2}^{0.5}\ \}}{2K_{st}} \tag{27}$$

where, K_{st} is a function of temperature, pressure, and ionic strength and was empirically correlated by Oddo and Tomson, represented as a logarithmic expression at Eq. (28).

$$\begin{aligned} \log K_{st} &= 1.86 + 4.5*10^{-3}T - 1.2*10^{-6}T^2 \\ &+10.7*10^{-5}P - 2.38I^{1/2} + 0.58I - 1.3*10^{-3}I^{1/2}T \end{aligned} \tag{28}$$

where, K_{st} is stability constant for combined sulfate scale minerals; $C_{Mg^{+2}}$ is Magnesium concentration measure in water (mol/L); $C_{Ca^{+2}}$ is Calcium concentration measure in water (mol/L); $C_{Sr^{+2}}$ is Strontium concentration measure in water (mol/L); $C_{Ba^{+2}}$ is Barium concentration measure in water (mol/L); $C_m = \Sigma(C_{Mg^{+2}} + C_{Ca^{+2}} + C_{Ba^{+2}} + C_{Sr^{+2}})$.

(2) Saturation Index of various sulfate scales

$$SI = log([Me][An]) + pKsp\ (T, P, I) \tag{29}$$

$$\begin{aligned} SI &= \log([Me][An]) + A + BT + CT^2 \\ &+DP + EI^{1/2} + FI + GI^{1/2}T \end{aligned} \tag{30}$$

where, *Me* is Mg^{+2}, Ca^{+2}, Sr^{+2}, or Ba^{+2}; *An* is SO_4^{-2}; Ksp is solubility product.

The following Table 9 of the different types of sulfate scales and their parameter values based on temperature, pressure, and ionic strength.

Table 9. Coefficients values in scaling prediction model

$pKsp$		A	B	C	D	E	F	G
Calcium Sulfate	Gypsum	3.47	1.8×10^{-3}	2.5×10^{-6}	-5.9×10^{-5}	-1.131	0.37	-2×10^{-3}
	Hemihydrate	4.04	-1.9×10^{-3}	11.9×10^{-6}	-6.9×10^{-5}	-1.66	0.49	-0.66×10^{-3}
	Anhydrate	2.52	9.98×10^{-3}	-0.97×10^{-6}	-3.07×10^{-5}	-1.09	0.5	-3.3×10^{-3}
Strontium Sulfate (celesite)		6.11	2×10^{-3}	6.4×10^{-6}	-4.6×10^{-5}	-1.89	0.67	-1.9×10^{-3}
Barium Sulfate (barite)		10.03	-4.8×10^{-3}	11.4×10^{-6}	-4.8×10^{-5}	-2.62	0.891	-2×10^{-3}

3. ABOUT SOFTWARE

The Scale Prediction Software features a user-friendly interface that allows users to easily enter the water analysis data. Once the data is entered, users have the option to select any of the five methods available to analyze the data.

The program provides a seamless experience, guiding users through the process of selecting the appropriate method for analysis. Users can choose from the Langelier Saturation Index (LSI), Ryznar Saturation Index (RSI), Calcium Carbonate Precipitation Potential (CCPP), Stiff and Davis Stability Index (SDI), or Oddo and Tomson Index (OTI).

Once a method is selected, the program utilizes the corresponding equation to process the input data and generate a prediction. The prediction will determine whether the water analyzed is prone to causing corrosion or scaling in industrial water systems.

The program ensures accuracy and reliability by leveraging extensive testing against real-world data from various sources, including the Great Man-Made River Project, Arabian Gulf Oil Company, Mellitah Oil and Gas Company, and Zueitina Oil Company. This rigorous testing process guarantees that the results generated by the software are dependable and can be trusted.

In summary, the Scale Prediction Software offers a user-friendly interface, allowing users to input water analysis data and select from five different analysis methods. The program then utilizes the chosen method to generate predictions regarding the potential for corrosion or scaling in industrial water systems. The software's accuracy is ensured through thorough testing against real-world data from reputable sources.

3.1 Description of the algorithm and the steps

Description of the algorithm and the steps involved. Since I cannot directly draw a flowchart, I will describe the flowchart for you.

(1) Start: The program begins.

(2) User interface: The user is presented with a user-friendly interface.

(3) Method selection: The user selects one of the five available methods for analysis: Langelier Saturation Index (LSI), Ryznar Saturation Index (RSI), Calcium Carbonate Precipitation Potential (CCPP), Stiff and Davis Stability Index (SDI), or Oddo and Tomson Index (OTI).

(4) Input data: The user enters the water analysis data, including temperature, pressure, specific gravity, pH, minerals (sodium, calcium, magnesium, potassium, barium, and nitrate), and negative anions (bicarbonate, chloride, sulfite, and nitrate).

(5) Analysis: The program uses the selected method's equation to process the input data and perform the analysis.

(6) Prediction: Based on the analysis, the program generates a prediction regarding the potential for corrosion or scaling in industrial water systems.

(7) Display result: The prediction result is displayed to the user.

(8) End: The program ends.

The study outlines the methodology used for analysis and prediction. The logical flow of the program and decision points are illustrated in Figure 5. The main interface of the software simplifies user interaction, as shown in Figure 6.

For the various indices used in the analysis:

i. Figure 7 illustrates the Oddo and Tomson Index, which helps evaluate the likelihood of scale formation.
ii. Figure 8 presents the Langelier Index, providing insight into water's tendency to form scale.
iii. Figure 9 depicts the Ryznar Index, used to assess the tendency of water towards scaling or corrosion.
iv. Figure 10 shows the Calcium Carbonate Precipitation Potential (CCPP), an important tool for determining water stability.
v. Figure 11 illustrates the analysis of concrete pipes for predicting their lifespan.

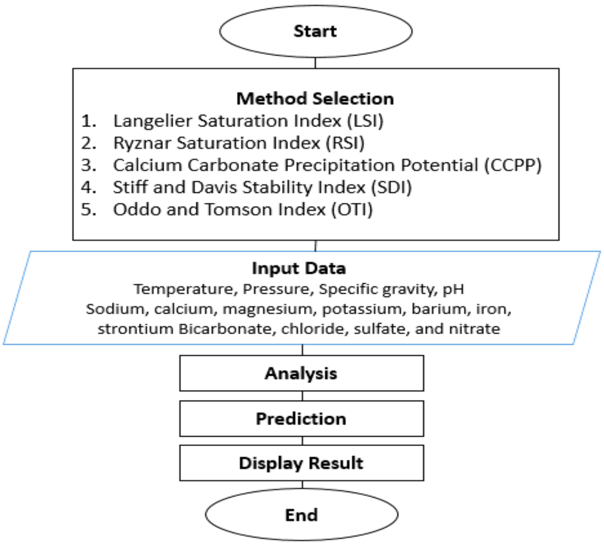

Figure 5. The flowchart for the methodology

Figure 6. The main interface of the software

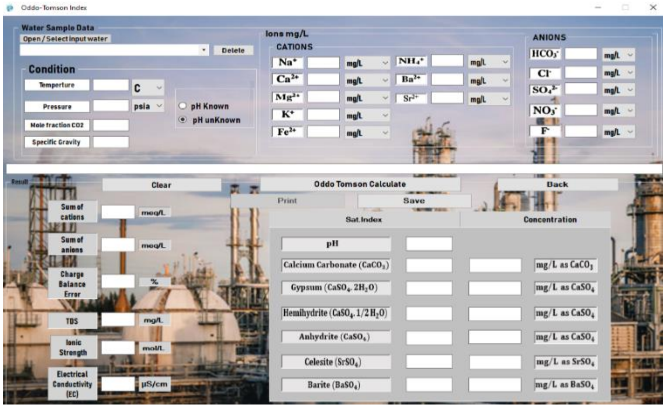

Figure 7. Oddo and Tomson Index

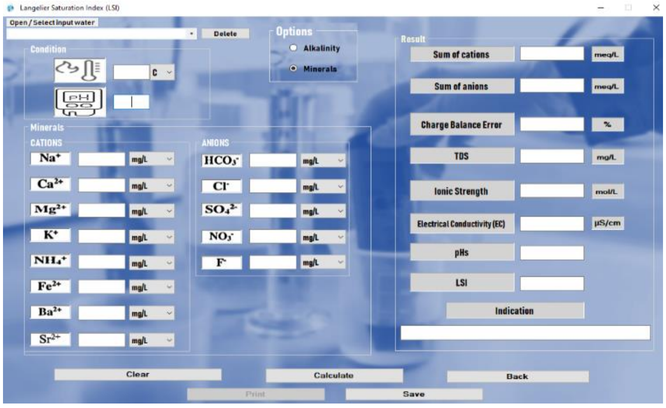

Figure 8. Langer index

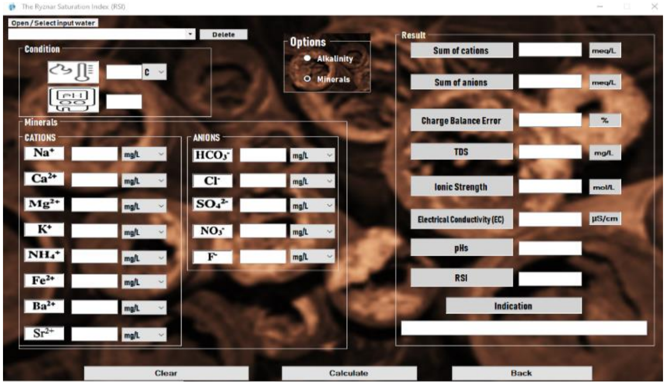

Figure 9. Ryzner index

Figure 10. Calcium Carbonate Precipitation Potential (CCPP)

● Dissolution Rate (K) unKnown & Calcium (Ca) at outlet Known
○ Dissolution Rate (K) Known & Calcium (Ca) at outlet unKnown
○ Dissolution Rate (K) unKnown & Calcium (Ca) at outlet unKnown

Diamter of Pipe	4	meter
Flow velocity	0.921	m/s
One pipe length	10000	meter
Total length of pipes	620	km
Density of concrete	2400	Kg/m3
Time period of inner core (concrete) in pipeline	50	Year
Calcium Concentration at the inlet of the pipe (C0)	18.7	mg/L as Ca
Calcium Concentration at the outlet of the pipe (CL)	19.66	mg/L as Ca
Calcium Carbonate Precipitation Potential (CCPP)	-65	mg/L as $CaCO_3$
Fraction of Calcium in concrete (σ)	0.102	

Figure 11. Predicate concrete pipe

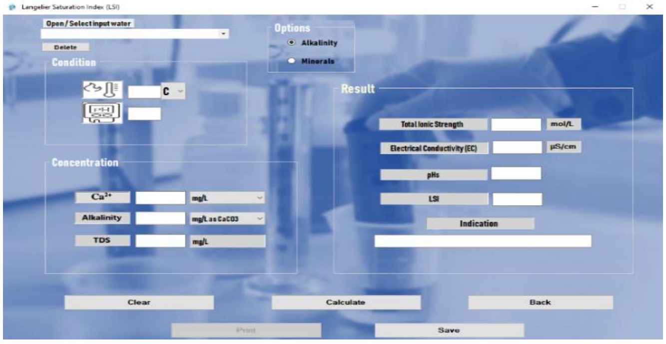

Figure 12. Langer index (2)

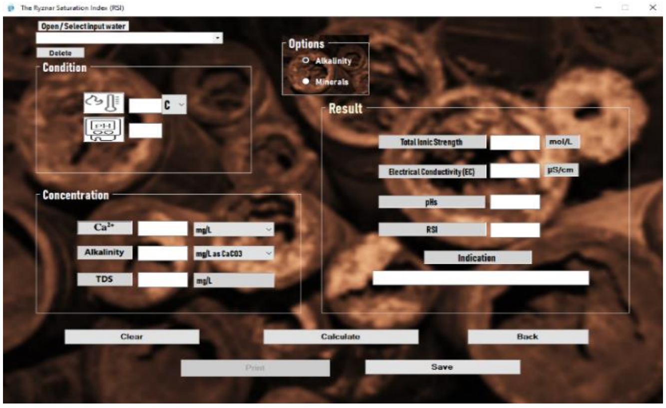

Figure 13. Ryzner index (2)

Figure 14. CCPP index (2)

Additionally, further details are provided in Figures 12-14:

i. Figure 12 shows the Langelier Index.
ii. Figure 13 displays the Ryznar Index.
iii. Figure 14 presents the CCPP Index.

4. RESULT

4.1 Great Man River Project (GMRP)

4.1.1 Predict water behavior in phase 2 (Jabal Al-Hasawnah fields)

The results obtained from the analysis of the water behavior in the Jabal Al-Hasawnah fields within the Great Man-Made River Project (GMRP) in Libya provide valuable insights into the scaling creation or absence of scaling, indicating corrosion or aggressive behavior in the water.

The software program developed using visual studio allowed for the application of various indices, including the Langelier Index (LSI), Ryznar Index (RSI), and Calcium Carbonate Precipitation Potential Index (CCPP). These indices were utilized to evaluate the presence of calcium carbonate deposits in several wells at Jabal Al-Hasawnah.

The findings, presented in Table 10, showcase the results of the analysis conducted using the developed software. These results offer a comprehensive understanding of the behavior of water in the Jabal Al-Hasawnah fields. By assessing factors such as pH or CO_2 concentration, pressure, specific gravity, alkalinity, and temperature, along with the concentrations of anions and cations, the software provided valuable predictions regarding potential scaling and corrosion.

These results contribute to the overall knowledge and understanding of managing water resources and infrastructure within the GMRP. By identifying the presence or absence of scaling and corrosion, stakeholders can make informed decisions and take appropriate measures to mitigate potential issues and optimize water system performance in the Jabal Al-Hasawnah fields.

Table 10 presents the inputs used to calculate the saturation index and predict water behavior in the Jabal Al-Hasawnah fields. These inputs were compared with the reported values by Brown & Root Company, as shown in the subsequent table.

The calculated values obtained from the software program closely matched the values reported by Brown & Root Company in the Great Man-Made River Project (GMRP). This indicates that the program is highly accurate in its predictions and analysis.

Table 10. Analysis of the Great Man River Project of NEJH

Coordinates			North East Jabal Al-Hasawnah					
			X	**Y**	**X**	**Y**	**X**	**Y**
			468120.9	**319266.4**	**4438872.2**	**3197839**	**449803**	**3179444**
WELL NO.			19		62		80	
Depth	meter		483.85		489.18		532.69	
Temp.	°C		32.3		34.1		31	
pH			6.29		7.18		7.06	
Langelier	Index	$PH - PHS$	-1.43		-0.49		-0.27	
Ryznar	Index	$2(PHS) - PH$	9.15		8.16		7.6	
CCPP	mg/L	$CaCO3$	-129		-10		-9	
EC	$\mu c/cm$	(Field)	1049		1197		2160	
TDS	mg/L	EC*0.65	682		778		1404	
CO_2	mg/L	$CO2$	40		14		24	
Dissolved Oxygen	mg/L	$O2$	2.9		4.1		4.5	
Calcium Hard	mg/L	$CaCO3$	200		206		410	
Total Hard	mg/L	$CaCO3$	327		298		600	
Sodium	mg/L	Na^+	119		110		211	
Potassium	mg/L	K^+	1.9		6		9.4	
Calcium	mg/L	Ca^{++}	80		82		164	
Magnesium	mg/L	Mg^{++}	31		21		46	
T.AlK	mg/L	$CaCO_3$	126		116		137	
Iron	mg/L	Fe^{++}	0.07		0.05		0.07	
Choride	mg/L	Cl^-	147		166		386	
Sulphate	mg/L	SO_4^{--}	115		135		323	
Nitrate	mg/L	NO_3^-	34		44.9		56.3	
Fluoride	mg/L	F^-	0.20		0.2		0.3	
TOT bact	Cell/mL		10		1		1	
Coliform	Cell/100mL		Nil		Nil		Nil	
SRB			P		p		p	
Total Cations	meq/L		12.01		21.5		19.9	
Total Anions	meq/L		11.65		22.4		18.72	

Table 11. Brown & Root's calculated values vs. software values

WELL NO.	GMRP Values (Brown &Root)			Software Values			
	LSI	RSI	CCPP (mg/L) as C_aCO_3	LSI	RSI	CCPP (mg/L) as C_aCO_3	Indication
19	-1.43	9.15	-129	-1.41	9.37	-128.9	No scaling, tendency of water to dissolve scale
62	-0.49	8.16	-10	-0.53	8.52	-10.3	No scaling, tendency of water to dissolve scale
80	-0.27	7.6	-9	-0.37	8.1	-8.8	No scaling, tendency of water to dissolve scale

Table 12. Dissolution of PCCP over 50 years-limestone aggregate (Phase 1 - Tazerbo water conveying)

Chainage of Pipeline (Km)	Inlet of the Pipe (Ca_0) (mg/L)	Outlet of the Pipe (Ca_L) (mg/L)	Loss of Pipe Wall Thickness (mm)
0	18.7	19.50	127.28
10	19.50	20.25	119.56
20	20.25	20.96	112.52
30	20.96	21.63	106.08
40	21.63	22.26	100.18
50	22.26	22.86	94.76
60	22.86	23.42	89.77
70	23.42	23.96	85.16
80	23.96	24.47	80.90
90	24.47	24.95	76.95
100	24.95	25.41	73.28
110	25.41	25.85	69.87
120	25.85	26.27	66.69
130	26.27	26.67	63.72
140	26.67	27.06	60.95
150	27.06	27.42	58.35
160	27.42	27.77	55.92
170	27.77	28.11	53.64
180	28.11	28.44	51.49
190	28.44	28.75	49.47
200	28.75	29.05	47.56
210	29.05	29.33	45.77
220	29.33	29.61	44.07
230	29.61	29.88	42.47
240	29.88	30.14	40.95
250	30.14	30.39	39.51
260	30.39	30.63	38.15
270	30.63	30.86	36.85
280	30.86	31.08	35.63
290	31.08	31.30	34.46
300	31.30	31.51	33.34
310	31.51	31.71	32.29
320	31.71	31.91	31.28
330	31.91	32.10	30.31
340	32.10	32.28	29.39
350	32.28	32.46	28.52
360	32.46	32.64	27.68
370	32.64	32.81	26.87
380	32.81	32.97	26.11
390	32.97	33.13	25.37
400	33.13	33.13	24.66
410	33.13	33.44	23.99
420	33.44	33.58	23.34
430	33.58	33.73	22.72
440	33.73	33.87	22.12
450	33.87	34.00	21.54
460	34.00	34.13	20.99
470	34.13	34.26	20.46
480	34.26	34.39	19.95
490	34.39	34.51	19.46
500	34.51	34.63	18.98
510	34.63	34.75	18.52
520	34.75	34.86	18.08
530	34.86	34.97	17.66
540	34.97	35.08	17.25
550	35.08	35.19	16.85
560	35.19	35.29	16.47
570	35.29	35.39	16.10
580	35.39	35.49	15.74
590	35.49	35.59	15.39
600	35.59	35.68	15.06
610	35.68	35.77	14.73
620	35.77	35.86	14.42

Furthermore, the results indicated that no scaling has occurred in any of the wells analyzed. This finding is significant as it suggests that the water in the Jabal Al-Hasawnah fields does not exhibit characteristics that lead to the formation of scaling, which is essential for maintaining the integrity and performance of industrial water systems.

The accurate matching of calculated values with the reported values by Brown & Root Company and the absence of scaling further validate the reliability and effectiveness of the developed software program. These results provide valuable insights into the behavior of water in the GMRP and support informed decision-making for water resource management in the Jabal Al-Hasawnah fields.

In order to validate the accuracy of the developed software tool, we compared its predictions with values calculated by Brown & Root for wells in the Great Man-Made River Project (GMRP). The comparison focused on three key indicators: Langelier Saturation Index (LSI), Ryznar Saturation Index (RSI), and Calcium Carbonate Precipitation Potential (CCPP). Table 11 presents a comparison between the values calculated by Brown & Root and those generated by the software for three specific wells.

As shown in the table, there is a close correlation between the two sets of values, indicating that the software is reliable in predicting the scaling potential of water. For each well, the LSI, RSI, and CCPP values are nearly identical, with slight variations that remain within acceptable margins of error. The table also includes an indication of the water's tendency to dissolve, further validating the software's practical utility in real-world scenarios.

4.1.2 Predicated attack on the conveyance pipeline - Phase 1 (Tazerbo)

Limestone aggregate

In the calculation the following base conditions have been assumed:

Diameter of pipe (m)=4
Flow velocity (m/s)=0.921
One pipe length (km)=10
Total length of pipes (km)=620
Density of concrete (kg/m³)=2400
Time period of inner core in pipeline (year)=50
Initial Calcium Concentration (mg/L)=18.7
Saturation Index (CCPP), (mg/L) as $CaCO_3$=-65
Dissolution rate (K). (m⁴/kg.s)=0.000305
Fraction of Calcium in concrete (σ)=0.381

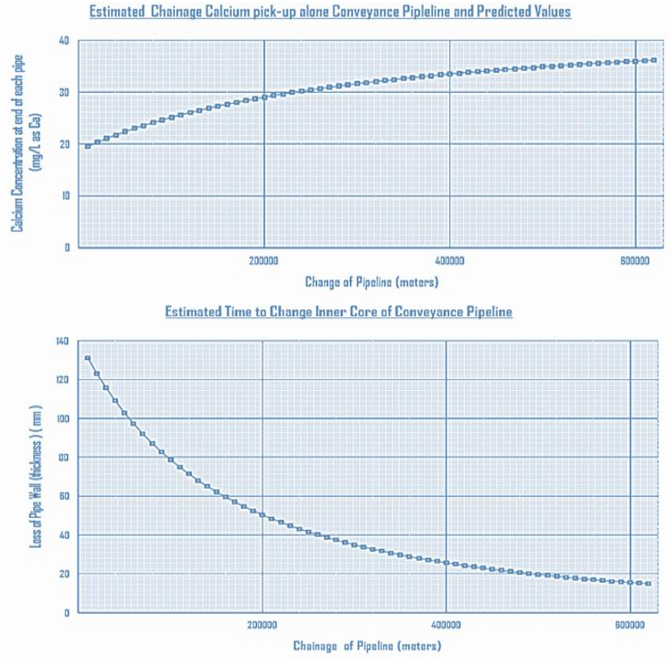

Figure 15. Comparison of the software values in a chart with the Brown & Root company values in Table 12 to estimate the time to destruction of the inner core of the limestone aggregate in the flow line

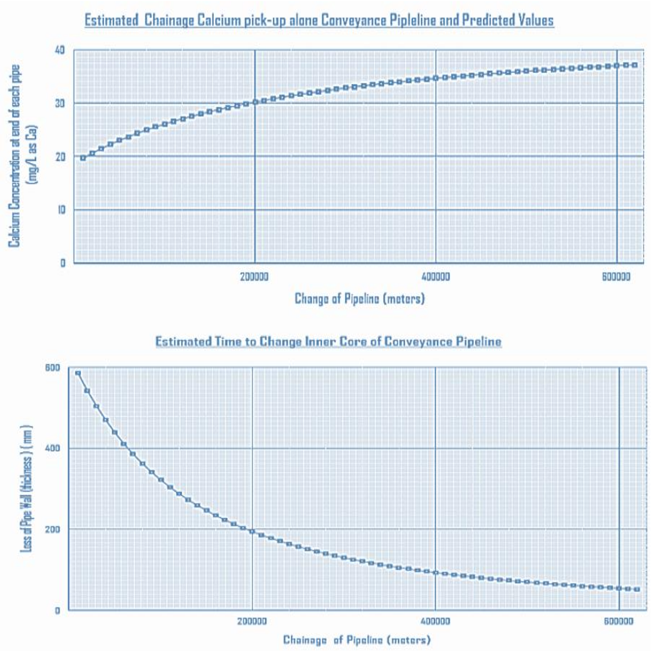

Figure 16. Comparison of the software values in a chart with the Brown & Root company values in Table 13 to estimate the time to destroy the inner core of the siliceous aggregate in the flow line

Figure15 illustrates a comparative analysis of the software-generated values against the values provided by Brown & Root Company, as detailed in Table 12. The chart aims to estimate the time to destruction of the inner core of the limestone aggregate in the flow line. This comparison highlights discrepancies and similarities between the two sets of data, providing insights into the longevity and durability of the limestone aggregate under specific flow conditions.

Siliceous aggregate

In the calculation the following base conditions have been assumed:

Diameter of pipe (m)=4
Flow velocity (m/s)=0.921
One pipe length (km)=10
Total length of pipes (km)=620
Density of concrete (kg/m³)=2400
Time period of inner core in pipeline (year)=50
Initial calcium concentration (mg/L)=18.7
Saturation index (CCPP), (mg/L) as $CaCO_3$=-65
Dissolution rate (K). (m⁴/kg.s)=0.00137
Fraction of calcium in concrete (σ)=0.102

Figure 16 presents a comparative analysis of the software-generated values alongside the values from Brown & Root Company, as shown in Table 13. The chart is designed to estimate the time required for the destruction of the inner core of the siliceous aggregate in the flow line. By juxtaposing these two data sets, the figure provides valuable insights into the performance and durability of the siliceous aggregate under similar conditions.

Table 13. Dissolution of PCCP over 50 years-siliceous aggregate (Phase 1 - Tazerbo water conveying)

Chainage of Pipeline (Km)	Inlet of the Pipe (Ca_0) (mg/L)	Outlet of the Pipe (Ca_L) (mg/L)	Loss of Pipe Wall Thickness (mm)
0	18.7	19.66	568.14
10	19.66	20.55	527.18
20	20.55	21.37	490.50
30	21.37	22.14	457.52
40	22.14	22.86	427.76
50	22.86	23.54	400.81
60	23.54	24.17	376.33
70	24.17	24.77	354.05
80	24.77	25.33	333.65
90	25.33	25.86	314.98
100	25.86	26.36	297.84
110	26.36	26.84	282.06
120	26.84	27.29	267.50
130	27.29	27.72	254.04
140	27.72	28.12	241.57
150	28.12	28.51	229.99
160	28.51	28.88	219.23
170	28.88	29.23	209.21
180	29.23	29.57	199.86
190	29.57	29.89	191.12
200	29.89	30.20	182.94
210	30.20	30.50	175.28
220	30.50	30.78	168.09
230	30.78	31.05	161.33
240	31.05	31.31	154.97
250	31.31	31.56	148.98
260	31.56	31.80	143.33
270	31.80	32.04	138.00
280	32.04	32.26	132.96
290	32.26	32.48	128.19
300	32.48	32.96	123.67
310	32.96	32.89	119.39
320	32.89	33.08	115.32
330	33.08	33.27	111.46
340	33.27	33.45	107.79
350	33.45	33.63	104.30
360	33.63	33.80	100.98
370	33.80	33.96	97.81
380	33.96	34.12	94.79
390	34.12	34.28	91.90
400	34.28	34.43	89.15
410	34.43	34.57	86.52
420	34.57	34.71	84.00
430	34.71	34.85	81.59
440	34.85	34.98	79.28
450	34.98	35.11	77.07
460	35.11	35.24	74.96
470	35.24	35.36	72.92
480	35.36	35.48	70.97
490	35.48	35.60	69.10
500	35.60	35.71	67.30
510	35.71	35.82	65.57
520	35.82	35.93	63.90
530	35.93	36.04	62.30
540	36.04	36.14	60.75
550	36.14	36.24	59.27
560	36.24	36.33	57.84
570	36.33	36.46	56.45
580	36.46	36.52	55.12
590	36.52	36.61	53.84
600	36.61	36.70	52.59
610	36.70	36.79	51.40
620	36.79	36.87	50.24

4.2 Arabian Gulf Oil Company and Mellitah Oil and Gas Company, besides Zueitina Oil Company

The analysis conducted in this study focused on predicting the behavior of highly saline water in the Sarir and AB Attifel fields, as well as Sabah, by the Arabian Gulf Oil Company (AGOCO), Mellitah Oil and Gas Company (MOGC), and Zueitina Oil Company.

To assess the scaling potential of various substances such as calcium carbonate, barium sulfate, calcium sulfate, and strontium sulfate, the Oddo-Tomson Index (OTI) was employed in this analysis. The OTI calculation provided insights into the likelihood of precipitation and scaling associated with these substances in the water of the mentioned fields.

By applying the OTI index, the study aimed to understand and evaluate the potential scaling issues that could arise in the highly saline water of the Sarir, AB Attifel, and Sabah fields. This information is crucial for oil and gas companies in managing and optimizing their operations, as scaling can significantly impact the efficiency and productivity of oil and gas production processes.

The results obtained from this analysis provide valuable insights into the scaling potential of different substances and contribute to a better understanding of water behavior in these fields. This information enables companies to make informed decisions and implement appropriate measures to mitigate scaling issues and ensure the smooth operation of their oil and gas production activities.

Table 14 presents a comparison between the saturation indices calculated by the software developed for this study and the values obtained from Jowfe Oil Technology Company's (JOF) Excel spreadsheet. This comparison aims to assess the accuracy and reliability of the software in predicting saturation indices. By evaluating the consistency between the software and the spreadsheet, determine the effectiveness of the software in providing accurate predictions.

Table 14. Values of excel spreadsheet for Jowfe Oil Technology vs. software values

Well No.	**WW.537**			
	Oddo-Tomson Index		**Conc. (mg/L)**	
Precipitation Salts	**JOF Company**	**Software**	**JOF Company**	**Software**
Calcium Carbonate ($CaCO_3$)	-0.067	-0.076	-30	0
Gypsum ($CaSO_4.2H_2O$)	-	-2.778	-1877.57	0
Hemihydrite ($CaSO_4.1/2H_2O$)	-	-2.93	-	0
Anhydrite ($CaSSO_4$)	-	-3.022	-	0
Barite ($BaSO_4$)	-	1.164	3.3	3.03
Celesite ($Sr\ SO_4$)	-	0	0	0
Well No.	**Well G.17**			
	Oddo-Tomson Index		**Conc. (mg/L)**	
Precipitation Salts	**JOF Company**	**Software**	**JOF Company**	**Software**
Calcium Carbonate ($CaCO_3$)	0.864	0.852	1631	1579.805
Gypsum ($CaSO_4.2H_2O$)	-	0.462	982.79	1342.28
Hemihydrite ($CaSO_4.1/2H_2O$)	-	-2.011	-	0
Anhydrite ($CaSO_4$)	-	-1.257	-	0
Barite ($BaSO_4$)	-	1.73	11.73	11.01
Celesite ($Sr\ SO_4$)	-	0	0	0
Well No.	**Well A.100**			
	Oddo-Tomson Index		**Conc. (mg/L)**	
Precipitation Salts	**JOF Company**	**Software**	**JOF Company**	**Software**
Calcium Carbonate ($CaCO_3$)	1.454	1.447	159	157.62
Gypsum ($CaSO_4.2H_2O$)	-	-8.049	-6950.625	-
Hemihydrite ($CaSO_4.1/2H_2O$)	-	-10.764	-	0
Anhydrite ($CaSO_4$)	-	-4.564	-	0
Barite ($BaSO_4$)	-	1.115	12.6	11.07
Celesite ($Sr\ SO_4$)	-	0	0	0

Table 15. Water analysis from oil wells for each of Sarir, Ab Attifel and Sabah fields

Component		**Sarir Field WW.537**	**Sabah Field Well G.17**	**Ab Attifel Field Well A.100**
pH		7	6.84	7
$T\ (F^0)$		89.6	110	268
Cond @ 25℃		1662	73700	-
S.G @ 25℃		1.0064	1.047	1.02
TDS	(mg/L)	823.4	49936	22022
$N\,a^+$	(mg/L)	101	14758	7260
Ca^{++}	(mg/L)	104	1680	920
Mg^{++}	(mg/L)	41.3	1665	199
Ba^{++}	(mg/L)	2	7	8
Sr^{++}	(mg/L)	0	0	0
Fe^{++}	(mg/L)	0.1	0.42	5.20
Cl^-	(mg/L)	280	27830.5	12850
CO_3^{--}	(mg/L)	0	0	0
HCO_3^-	(mg/L)	231	1244.4	100
OH^-	(mg/L)	0	0	0
SO_4^{--}	(mg/L)	64	2750	680
H_2S	(mg/L)	0	0	0
O_2	(mg/L)	2	-	-
CO_2	(mg/L)	57	-	240
Press	(Psi)	76	150	1000

The values closely align, it indicates that the software is performing well and generating reliable saturation indices.

This comparison provides valuable insights into the performance and accuracy of the software used in this study. It helps validate the reliability of the software in predicting saturation indices and reinforces its credibility as a tool for analyzing water behavior in oil and gas fields.

The comparison between the calculated values of Jowfe Oil Technology Company (JOF) and the values obtained from the software reveals a high level of similarity, indicating the software's reliability and accuracy in predicting saturation indices. This finding is significant as it assures JOF of the effectiveness of the software in analyzing water behavior in oil and gas fields.

As shown in Table 15, the water analysis from the Sarir, Ab Attifel, and Sabah fields reveals significant variations in chemical components across the different wells. For instance, the pH levels range from 6.84 in the Sabah Field to 7 in both the Sarir and Ab Attifel Fields. Additionally, the total dissolved solids (TDS) indicate substantial differences, with the Sabah Field exhibiting a TDS of 49,936 mg/L, while the Sarir Field shows a much lower TDS of 823.4 mg/L. This data highlights the varying water quality and potential implications for operational efficiency in these fields.

Upon examining the results presented in Table 14, it becomes evident that scaling tendencies exist in all wells analyzed. These scaling tendencies are characterized by the presence of specific substances in each well:

1. In the Sarir field well of Arabian Gulf Oil Company (AGOCO), the predominant scaling substance is barium sulfate.
2. The Sabah field well of Zueitina Oil Company (ZOC) exhibits scaling potential in the form of calcium carbonate, barium sulfate, and calcium sulfate (gypsum).
3. The Abu Atfal field well of Mellitah Oil and Gas Company (MOGC) demonstrates scaling tendencies with calcium carbonate and barium sulfate.

Identifying the specific substances responsible for scaling in each well is crucial for effective mitigation and management strategies. By understanding the scaling potential associated with these substances, JOF and other relevant companies can implement appropriate measures to prevent or alleviate scaling issues, thereby optimizing their oil and gas production processes.

Overall, the reliability of the software in predicting saturation indices, combined with the identification of scaling tendencies in the analyzed wells, provides valuable insights for JOF and other companies in managing scaling-related challenges and ensuring the smooth operation of their oil and gas fields.

5. DISCUSSION

Certainly, every software tool has its limitations and constraints, and it is important to address them in the discussion section of the paper. In the case of the scale prediction software developed in this study, there are a few known limitations that should be acknowledged.

Firstly, the accuracy and reliability of the software heavily rely on the quality and accuracy of the input data. Any inaccuracies or uncertainties in the input data can potentially affect the accuracy of the predictions made by the software. Therefore, it is crucial to ensure the input data is collected and measured with precision.

Secondly, the software's performance may vary depending on the specific water chemistry and conditions of the system being analyzed. It is possible that certain scenarios or extreme conditions might not be adequately captured by the software's algorithms, leading to less accurate predictions. It is important to acknowledge that the software's performance may be more optimized for certain scenarios and may have limitations in others.

Additionally, it is essential to note that the software's predictions are based on mathematical models and algorithms, which are simplifications of complex real-world phenomena. While efforts have been made to develop accurate models, there might still be inherent limitations and assumptions within these models that can affect the precision of the predictions.

Moreover, the software's effectiveness in predicting scaling and corrosion tendencies is primarily focused on the substances and indices evaluated in this study, namely calcium carbonate, barium sulfate, calcium sulfate, and strontium sulfate, along with the selected indices such as LSI, RSI, CCPP, SDI, and OTI. Other substances or indices not considered in this study may not be accurately predicted by the software.

Lastly, like any software tool, updates and improvements may be required over time to address any identified limitations or enhance the software's performance. It is important to recognize that the software's capabilities may evolve as further research and development are conducted.

6. CONCLUSIONS

In conclusion, this study emphasizes the significant challenges posed by scale formation and corrosion in industrial water usage, particularly in the petroleum industry. These issues can have detrimental effects on production operations.

To address these challenges, the study evaluated five different indices as indicators of scaling formation and corrosion tendencies. The Langelier Saturation Index (LSI), Ryznar Index (RSI), Calcium Carbonate Precipitation Potential (CCPP), Stiff and Davis Index (SDI), and Odd-Thomson Index (OTI) were examined. The LSI, RSI, and CCPP indices were found to be suitable for water with Total Dissolved Solids (TDS) below 10,000, while the SDI and OTI indices were more appropriate for brine water with TDS levels exceeding 10,000.

Among these indices, the CCPP method demonstrated higher accuracy in estimating calcium carbonate levels compared to the LSI and RSI indices. The OTI index emerged as the most accurate method, considering its inclusion of pressure in calculations and its ability to indirectly determine pH based on carbon dioxide and bicarbonate concentrations in water.

The developed scale prediction software was tested using data from the Great Man-Made River Project (GMRP), in collaboration with the Arabian Gulf Oil Company, Mellitah Oil and Gas Company, and Zueitina Oil Company (AGOCO, MOGC, and ZOC). Visual Basic was chosen as the programming language for the software due to its ease of use and accessibility.

The resulting software is designed to be user-friendly and simple, encouraging proactive measures in industrial operations to prevent scale deposition and corrosion. It provides a valuable tool for early detection and prevention of scaling issues, enabling industries to effectively manage water systems, reduce operational costs, and optimize performance.

In summary, this research highlights the importance of understanding and managing scale formation and corrosion risks in industrial water usage. The scale prediction software offers a practical solution for predicting and managing scaling issues, facilitating proactive steps in industrial operations. By leveraging this tool, industries can prevent scale deposition and corrosion, leading to improved operational efficiency and cost savings.

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