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Optimization of electrochemical desalting in crude oil refinery

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Abstract - Résumé

The petroleum refining industry transforms crude oil into various components such as diesel, jet fuel, and petroleum gases. One of the essential preliminary steps is electrochemical desalting—also known as cells—which uses electrochemical cells to remove salts from crude oil. These cells typically consist of an anode and a cathode; when an electric current is applied, it triggers ion exchange and facilitates salt removal. This is critical because salts can cause corrosion in processing equipment, reduce refining efficiency, and degrade product quality. The aim of this work is to optimize salt and water removal efficiency in an industrial crude oil desalting plant under steady-state conditions. Operational data from the plant were collected and used for simulation. The comparison between simulation and real data confirmed the accuracy of the simulation model. The results indicate that the electric field significantly impacts process efficiency, improving water removal efficiency from 93% to 98%.

1. INTRODUCTION

The petroleum refining industry converts crude oil into a range of valuable products, including diesel, jet fuel, and petroleum gases [1]. Crude oil - the cornerstone of modern industrial civilization - is a complex mixture of hydrocarbons along with various impurities, notably inorganic salts [2]. These salts, primarily chlorides of calcium, magnesium, and sodium, present significant challenges during the refining process. Their presence can lead to equipment corrosion, fouling, and reduced efficiency in downstream processing units. Traditionally, desalting is achieved through the use of chemical demulsifiers combined with gravitational separation techniques [3].

In recent years, electrochemical desalting - also known as electrode-salting—has gained attention as an innovative and environmentally friendly alternative [4]. This method leverages electrochemical principles to remove salts and water more efficiently and selectively than conventional approaches [5]. It enhances the desalting process by promoting the migration of charged ions under an applied electric field, thereby facilitating their removal from the crude oil matrix.

2. RESOURCES AND METHODS

The study used Arabian light crude oil and investigated electrochemical desalting by mixing the crude with wash water to form an emulsion treated in an electrochemical cell with an anode and cathode. The applied electric field promoted ion migration and water droplet coalescence, enabling simultaneous salt and water removal. Key operational parameters varied were temperature (98–133 °C), retention time (10–30 min), pH (2.5–13.2), and electric field intensity (0.1–3 kV/cm). Parametric analysis showed that optimal efficiency (~98%) was achieved under moderate electric fields (~0.14 kV/cm), a pH near 10, and intermediate temperatures, reducing both energy consumption and CO_2 emissions.

2.1. Industrial Process

As shown in Fig.1, the process begins with the introduction of crude oil into the desalting unit. This crude oil typically contains dissolved and suspended salts, as well as water and other impurities. To enhance the separation of salts and water from the crude oil, an emulsion is formed by mixing the crude oil with water [6]. This emulsion facilitates the subsequent electrochemical treatment by increasing the contact area between the crude oil and the water phase. Within the desalting unit, electrodes are strategically positioned [7]. These electrodes are connected to a power source to generate an electric field within the emulsion. The electric field induces the migration of charged species, including salt ions, toward the oppositely charged electrodes. As the electric field influences the movement of charged particles, salt ions migrate towards the electrodes [8]. This migration leads to the selective separation of salts from the crude oil.

The charged nature of the ions makes them responsive to the electric field, facilitating their removal. The crude oil, now separated from a significant portion of salts, progresses through a separation chamber [9]. In this chamber, the effects of the electric field are maximized to ensure efficient removal of remaining salts and water. Electrochemical desalting not only targets salts but also aids in the removal of water from the crude oil. The electric field helps break emulsions formed during the mixing process, facilitating the separation of water and preventing its interference in downstream processes. The final output of the electrochemical desalting process is desalted crude oil (Fig. 2). This purified crude oil contains significantly reduced levels of salts and other impurities, making it more suitable for further processing in the refining units downstream [10].

Electrostatic fields generate forces that can create conditions for improved coalescence of water droplets, resulting in improved separation of water and metal from the crude oil.

Reaction into desalting unit

• Hydrolysis of salts:

$CaCl_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HCl$ (I)

$MgCl_2 + 2H_2O \rightarrow Mg(OH)_2 + 2HCl$ (II)

• Corrosion:

$2HCl + Fe \rightarrow Fe^{2+} + 2Cl^- + H_2$ (III)

• Presence of (H2S):

$H_2S + Fe \rightarrow FeS + H_2$(IV)

In presence of (H_2S), (HCl) produced by (I) and/or (II) reacts with (FeS) formed by (IV) as follows:

$2HCl + FeS \rightarrow Fe^{2+} + 2Cl^- + H_2S$ (V)

The objective of this study is to investigate and optimize the desalting process of crude oil by exploring non-traditional parameters. The focus is on the impact of demulsifier type and dosage, operating temperature, and water pH on desalting efficiency. The experiments were conducted using crude oil samples collected from an Iranian offshore platform.

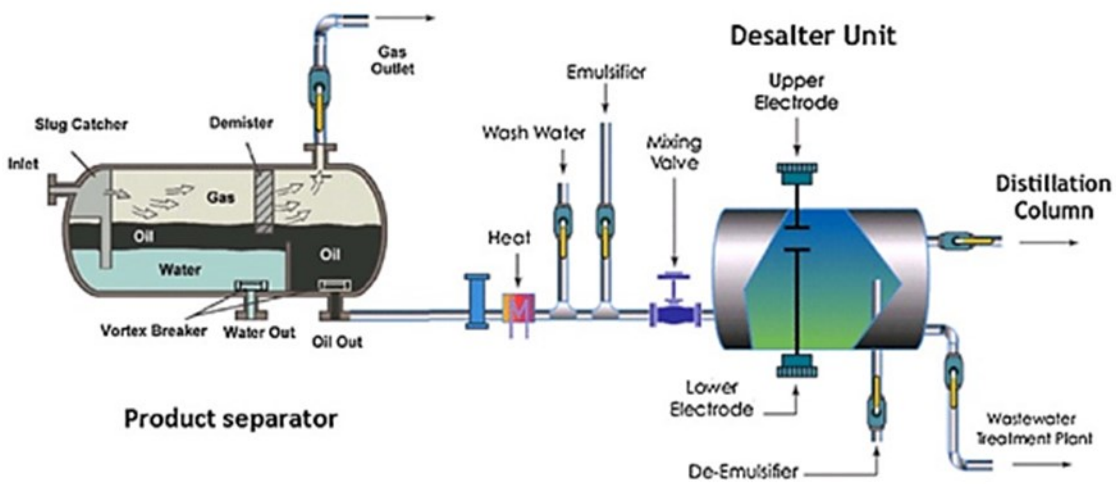

Figure:1. Electrochemical desalting crude oil system process.

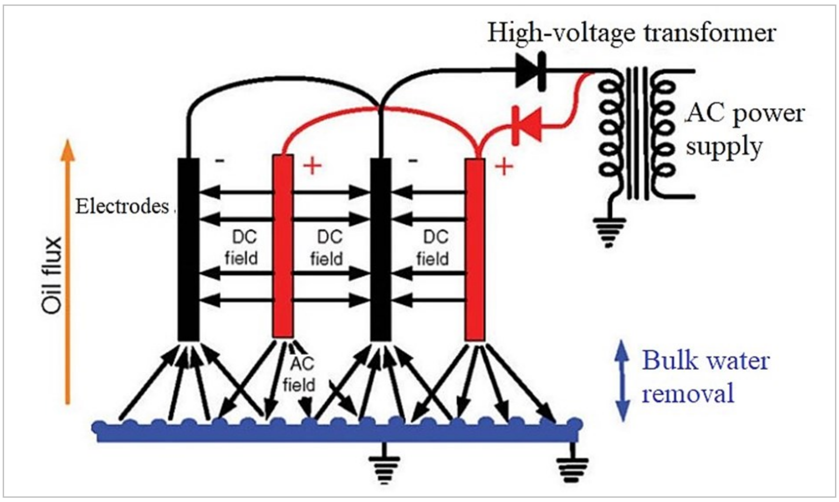

Figure 2: Electrochemical mechanism into desalting unit

3. RESULTS AND DISCUSSION

Table 1 presents the characteristics of the crude oil entering the desalting facility. It is well established that desalting efficiency improves when key operating conditions—such as temperature, electric field strength, the volume of fresh water, and the oil–water interface pH—are properly optimized. In this research, a non-conventional approach was adopted to enhance the performance of the desalting process. Specifically, the study focused on optimizing the type and amount of demulsifier, operating temperature, and the pH of the wash water using crude oil sourced from an Iranian oil platform.

3.1. Parameters study

Table 2 summarizes the operational ranges of the key parameters investigated in this study. These parameters were varied in order to evaluate their individual and combined effects on desalting efficiency. The temperature was adjusted between 98°C and 133°C to simulate typical industrial conditions. Retention time, which influences the contact period between phases, was varied from 10 to 30 minutes. The pH

Table 1. Crude oil type Arabian Light Analyse

Crude oil	Arabian light
Density API 15.6°C (°API)	32.3
Kinematic Viscosity, 50°Cmm²/s (cSt)	4.76
Carbon residue (Wt)	4.23
Pour point °C	-30
Total Nitrogen (ppm)	0.1
Sulfuret (wt%)	1.7
Salt and Water (Vol%)	0.05
Salt (Chloride ions, mg/L)	33
H/C (mole/mole)	1.84
D (g/cm3)	0.83

Table: 2 Parameters study

Parameters	Operation Ranges
Temperature	98-133°C
Retention time	10-30 min
pH	2,5- 13,2
Electric field	0.1-3

ranged from acidic (2.5) to highly basic (13.2), allowing an assessment of its impact on emulsion stability and salt solubility. Finally, the applied electric field ranged from 0.1 to 3 kV/cm, covering both low and high-intensity fields to identify optimal electrostatic conditions for salt removal.

3.1.1. Influence of pH: The pH of the crude oil or the emulsion can have a significant impact on the electrochemical desalting process [11]. The pH of the system can influence the charged state of the ions, the efficiency of separation, and the overall effectiveness of the desalting process. Here are some key considerations regarding the effect of pH on electrochemical desalting. Depending on the specific electrochemical desalting setup, there may be an optimal pH range for achieving the highest efficiency in salt removal. Scientists and engineers carefully consider the pH as part of the overall process optimization [12]. The pH of the crude oil or emulsion is a critical parameter in electrochemical desalting. It affects the ionization of salts, electrostatic interactions, and the overall efficiency of the process. Optimization of pH conditions is essential to achieve effective salt removal and to ensure the compatibility of the desalted crude oil with downstream refining processes.

3.1.2 Temperature: The temperature plays a significant role in the electrochemical desalting process, influencing various aspects of the operation and efficiency of the system. Electrochemical processes, in general, are often sensitive to temperature changes. Here are some key considerations regarding the effect of temperature on the electrochemical desalting process. Temperature has a direct impact on reaction rates. In electrochemical desalting, the movement of ions, their migration towards electrodes, and their subsequent separation are processes that may exhibit temperature dependence. Generally, higher temperatures can accelerate these processes [13].

3.1.3. Retention Time: Retention time, or the duration that crude oil spends in the electrochemical desalting unit, is a critical parameter that influences the efficiency and effectiveness of the desalting process [14]. The retention time directly affects the extent of contact between the crude oil and the electrochemical environment, influencing the separation of salt ions and water. Here are some key considerations regarding the effect of retention time on the electrochemical desalting of crude oil. The retention time can be adjusted based on variations in crude oil properties, flow rates, and processing requirements. This provides operational flexibility to adapt the desalting unit to changing conditions

3.1.4. Electrostatic Field: If the voltages go up and current flow becomes excessive then the desalting operation becomes costly. On the other side, if the voltage drops then demulsification also drops down, resulting in poor desalting efficiency [15].

The efficiency of electrochemical desalting of crude oil is closely dependent on temperature, pH, and the intensity of the applied electric field. A moderate increase in temperature (up to around 120 °C) reduces the viscosity of the oil and increases ionic mobility, facilitating the migration of chloride ions and the coalescence of water droplets, which improves phase separation. However, excessively high temperatures can lead to the formation of stable interfacial films and increase energy consumption, thus reducing the overall efficiency of the process. The pH of the aqueous phase also plays a crucial role: in a slightly basic environment (pH around 10), emulsion stability decreases, promoting demulsification and the separation of brine, whereas an acidic pH increases corrosion and the solubility of metallic salts, making their extraction more difficult. Finally, the application of an appropriate electric field (around 0.14 kV/cm) induces

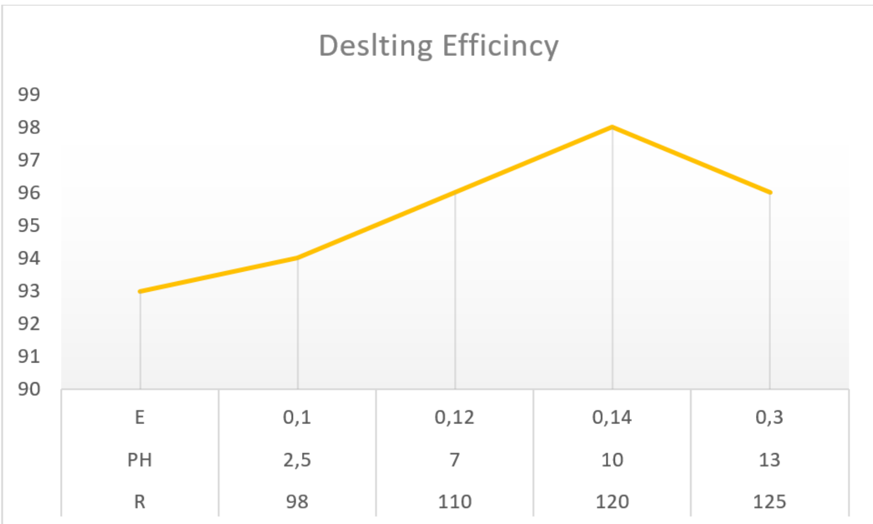

Figure 3. Optimum of desalting efficiency in function of key parameters

polarization and coalescence of water droplets, resulting in desalting efficiencies of up to 98%. On the other hand, an excessively strong field can cause local turbulence and partially reform the emulsions. The interaction among these three parameters shows that an optimal balance — moderate electric field, intermediate temperature, and slightly basic pH achieves the highest desalting efficiency while reducing energy consumption and CO_2 emissions.
Figure 3 presents the experimental results obtained in this study, showing how desalting efficiency varies with key operational parameters, namely electric field intensity (E), pH, and the retention time (R). The data reveal a clear trend: as the electric field increases from 0.1 to 0.14, desalting efficiency improves significantly, peaking at 98%. This enhancement is attributed to more effective ion migration under a stronger electric field. The corresponding increase in pH, from 2.5 to 10, may have further contributed to improved demulsification and salt extraction. Beyond E = 0.14, however, the efficiency slightly declines to 96%, possibly due to overexposure to the electric field causing re-emulsification or instability in the separation system. These findings confirm the existence of an optimal operating range that maximizes desalting performance under industrial conditions.

4. CONCLUSION

The application of a parametric sensitivity analysis enabled the optimization of process conditions. Through this approach, it was possible to achieve substantial reductions in both operating costs and environmental impact. The optimized configuration resulted in a 14% decrease in operational costs and a 24% reduction in CO_2 emissions, highlighting the potential of this technology for more sustainable refinery operations.
These findings demonstrate not only the technical viability but also the economic and environmental advantages of electrochemical desalting. Further work may include scale-up studies, integration with other separation technologies, and the use of artificial intelligence for process control and predictive maintenance to enhance performance in real-time industrial applications.

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