Produced Water Effluent in East Baghdad Oil Field: Treatment for Oil Recovery Application

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Abstract

This study focuses on the problem of produced water (PW) in Midland Oil Company (Md.O.C)-East Baghdad Oil Field (EBOF). This type of water is produced with huge amounts in the company's subsidiary fields annually. For safely reinjection application, the collected produced water sample was subjected to several bench scale sequences of treatment including (Coagulation, Flocculation, Filtration, dissolved oxygen removing and disinfection of bacteria) to make it appropriate for reinjection. The target parameters for treatment were (pH, Oil and grease, Turbidity, suspended solids (TSS), Dissolved oxygen (DO) and Bacteria). The obtained results from final treatment stage proved that the treated parameters of water are proper to use the water for injection to increase the recovery of oil. The concentration of oil and grease was decreased from 74 mg/L in the raw water sample to less than 5mg/L after treatment. The total suspended solids (TSS) and turbidity were reduced from 164 mg/L and 45 Nephelometric Turbidity Unit (NTU) to trace and 0.15mg/L respectively. A dissolved oxygen (DO) was remediated to be 0.7mg/L from initial concentration (2.4 mg/L) via using a 100 mg/L sodium sulfite solution as oxygen scavenger. A sand filter proposed design was set and used successfully to get the required specifications of the treated produced water using in the oil recovery.

Keywords: Produced water, Coagulation, Flocculation, Jar test, Filtration, Dissolved Oxygen removing, and Oil Recovery.

Journal of Water Resources and Geosciences
Vol. 4, No.1, 2025

الماء المصاحب المنتج في حقل شرقي بغداد: المعالجة لغرض الاستخلاص النفطي

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الخلاصة

تركز هذه الدراسة على مشكلة المياه المصاحبة (PW) في شركة نفط الوسط (Md.O.C) – حقل شرق بغداد النفطي (EBOF) حيث يطرح هذا النوع من المياه بكميات هائلة في الحقول التابعة للشركة سنوياً كنتيجة لاستخلاص النفط. ومن أجل إعادة الحقن بشكل آمن، تم إخضاع العينة المسحوبة من المياه المصاحبة الى مجموعة من المعالجات والتي شملت عمليات (التخثر، التلبيد، الترشيح، إزالة الأكسجين المذاب وتطهير البكتيريا) لجعلها مناسبة لإعادة الحقن. كانت العوامل المستهدفة للمعالجة هي (pH، الزيوت والشحوم، العكارة، المواد الصلبة العالقة (TSS)، الأكسجين المذاب (DO) والبكتيريا). أثبتت النتائج التي تم الحصول عليها من مرحلة المعالجة النهائية أن مواصفات المياه المعالجة كانت مناسبة لاستخدامها لزيادة الاستخلاص النفطي حيث انخفض تركيز الزيوت والشحوم من 74 ملجم / لتر في عينة المياه الخام إلى أقل من 5 ملجم / لتر بعد المعالجة، كذلك فان إجمالي المواد الصلبة العالقة (TSS) تم خفضها من 164 ملغم/لتر إلى 0.15 ملغم/لتر والعكورة من 45 وحدة تعكر نيفيلومترية (NTU) الى الى اقل من 1. تمت معالجة الأكسجين المذاب (DO) ليصبح 0.7 ملجم / لتر من التركيز الأولي (2.4 ملجم / لتر) عن طريق استخدام محلول كبريتيت الصوديوم بتركيز 100 ملجم / لتر كمادة ساحبة للأكسجين. تم وضع تصميم مقترح للمرشح الرملي واستخدامه بنجاح للحصول على المواصفات المطلوبة للمياه المعالجة والممكن استخدامها في عملية الاستخلاص النفطي.

الكلمات المفتاحية: الماء المصاحب ، التخثير ، التلبيد ، فحص الجرة، الترشيح ، ازالة الاوكسجين، الاستخلاص النفطي.

1. Introduction

Produced water (PW) is a huge amount of water that is produced as a result of oil drilling. It's a byproduct of oil drilling (Shakir, 2013). Water trapped in subterranean reservoir rocks that is transported to the surface with crude oil and gas is known as PW. It contains dispersed oil droplets, dissolved organic compounds, and significant amounts of anion, such as Carbonate, Bromide, and Sulfate, in addition to increased concentration of heavy metals such as Barium, Uranium, Cadmium, Chromium, Strontium, and Lead (Perry & Gigliellok, 1990). The physical and chemical qualities of produced water differ significantly depending on the field's geographic location, the geological background of the source and host with which it has been in contact for thousands of years, and the type of hydrocarbon product being produced(Oboh et al., 2009). The amount of water produced is seven to eight times that of the oil produced (Igwe et al., 2013).For the studied oil field, the amount of produced water is about 1.5% to 2.7% of the oil-water mixture brought to the surface . Due to the presence of high-concentration harmful chemicals in untreated generated produced water, a variety of issues arise, and improper disposal of oily sludge can constitute a major threat to the receiving environment. Oily sludge can alter soil's physical and chemical properties, resulting in morphological changes. On contact, the oily sludge contaminated soils may induce nutritional deficiency, reduced seed germination, and limited growth or death of plants. Oily sludge components can be fixed in soil pores, adsorbed onto the surface of soil mineral elements, or create a continuous cover on the soil surface due to their high viscosity. As a result, soils' hygroscopic moisture, hydraulic conductivity, and water retention capacity would be lowered. Higher molecular weight components in sludge, as well as their degradation products, may linger at the soil surface and produce hydrophobic crusts, reducing water availability and limiting water/air exchange (Hu et al., 2013). Generally, produced water is constituted of dissolved and dispersed oil components, dissolved formation minerals, production chemicals, dissolved gases (including CO_2 and H_2S) and produced solids(Hameed & Abbas, 2021). There is a considerable fluctuation in the degree of its organic and inorganic content owing to geological formation, lifespan of the reservoir and the kind of hydrocarbon produced. Although most produced water is reused and reinjected into the subsurface after a specific treatment to improve oil recovery, huge volumes of produced water are discharged directly into the environment. The presence of oil as a result of the complex composition of produced water has shown the ecological concerns associated with crude oil pollution in recent years(Cooper et al., 2021) . However, having a thorough understanding of the properties of produced water might help operators enhance productivity. Producers can also calculate well-treatment chemicals and identify reservoir trouble regions by understanding the components of produced water (Jiang et al., 2022). The most common method of dealing with produced water is to re-inject it into the formation water (Kassab et al., 2021). To get better outcomes, produced water re-injection (PWRI) requires modified treatment before injection, although the infectivity decreases with time(Dudek et al., 2020). Currently, PW is generated at EBOF by the process illustrated in Figure (1) where the crude Oil collected from the wells is passed into the dehydrator. In this stage; fresh water is injected for washing the crude oil to remove the suspended solids and salts. In the second stage of the treatment, oil is pumped into the desalter, and water is also injected.

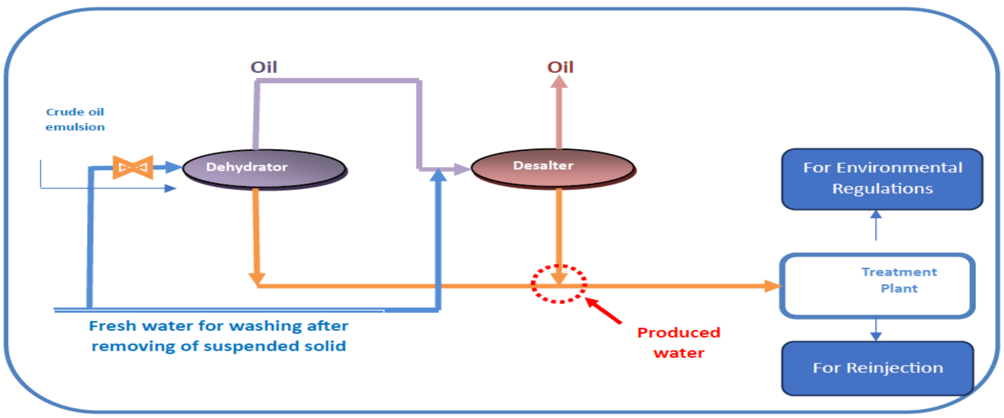

Figure (1): The separation process of oil in EBOF

The generated produced water is discarded into the evaporation pond Figure (2) causing possible negative effects on the land, groundwater, air, and also esthetic pollution. In the other hand, it is expected that the field would need huge quantities of water for injection to maintain the productivity of oil in so-called secondary oil recovery.

Figure (2): Evaporation Pond in EBOF

The specifications of water for reinjection application differ from reservoir to another. This is due to the rock type and its role in porosity and permeability in the reservoir that effected by the water injection type, temperature and pressure within the reservoir that affect the solubility of certain chemicals in the injected water, and reservoir fluids that interferes with injected water, but generally the typical specifications of water for reinjection applications without causing damage to the reservoir are illustrated in Table (1). The reservoirs can be negatively affected by injection poor quality water (Bader, 2007).This research focus on treatment of the produced water resulted in Midland Oil Company (Md.O.C)-East Baghdad Oil Field (EBOF) where a huge quantities are discarded into evaporation ponds daily causing serious problems to the environment , and also to provide a qualified water to maintain the oil production .

Table (1): Proper Specifications of Water for Oil Recovery (Kuraimid et al., 2013)

Specification	Typical Specifications for Reinjection Application
pH	6.5-7.5
TSS (mg/L)	Less than 2
Turbidity (NTU)	Less than 1
Oil and Grease (mg/L)	Less than 5
Total Iron (mg/L)	Less than 5
Dissolved Oxygen (DO), (mg/L)	Less than 0.02
Microbial Activity (Present or Absent)	Absent

To avoid formation damage and hence maintain good and long-term injectivity, the injected water should be appropriate with the formation water and free of suspended particles and oil (Al-Taq et al., 2017).

2. Material and Methods

In this research, a produced water (PW) sample (30 L) was collected from EBOF in the point sampling of degassing station and a bench-scale treatment of PW was applied to obtain some proper specifications of water for reinjection purposes. pH, Oil and grease, Turbidity, suspended solids (TSS), and dissolved oxygen will be tested and treated in this work. The studied produced water sample showed a little oil content, so the oil treatment stage will not be mentioned. A polyaluminium chloride(PAC) (Duan & Fedler, 2021), aluminum sulfate (ALM) (Jabbar & Alatabe, 2021), and ferric chloride hexahydrate(FCH) (Al-Ghouti et al., 2019) were used as coagulant agents while polyacrylamide (PAA) (Salih et al., 2021) was used as flocculant to investigate the optimum doses to reduce the turbidity and TSS.

A conducting of a jar test method in the lab is considered as a simulation method of clarification of water used in any full-scale treatment plant. The jar test device used in this research is Armfield - SW6 / England. A stock solution (10000 mg/L) of PAC, ALM and FCH using as additive to flocculate the turbidity were applied to prepare different diluted concentrations and also a stock solution of a polyacrylamide (1000mg/L) was used for the same purpose. Solutions of sodium hydroxide (25%) and hydrochloric acid (1:1) were used to adjust pH value of the raw PW to about 7 by using pH meter Scott – Lab850 (Germany). The dose ranges of coagulants were (10-70 mg/L), (10-50mg/L), and (10-60mg/L) for PAC, Alm, and FCH respectively. The concentration of the PAA was fixed as 2 mg/L for the all-jar test experiments. In jar test, Settling Velocity Criterion is very important to determine where is the removing of suspended solids is well or not (Tlaiaa et al., 2020). When the settling velocity is more than 50 mm/min it refers to an excellent sedimentation of the suspended solids. The range 20 – 50 mm/min indicates a good status of the sedimentation. A poor sedimentation less than 20 mm/min requires a modification in the jar test process. The total suspended solids (TSS) and turbidity were measured in the experiments via water filtration apparatus (0.45 mm filter paper) and WTW-Turb 355T meter (Germany) respectively.

To remove the residual suspended solids after coagulation and flocculation combination process, a sand filter with two different materials (Anthracite and Sand) was used to get the required specifications of TSS, turbidity and particle size for treated PW to be rejected safely in the reservoir in the oil recovery process. The media of sand filters consist of the materials illustrated in Figure (3).

Figure (3): Media of sand filter

The media of sand filters (Sand and Anthracite) were provided by Alnawafiz Company for sand and gravel production –Baghdad. The particle sizes of the materials were tested in PRDC laboratories and the diameters by volume were 50:983 and 50:1770 micron for anthracite and sand respectively. In order to simulate the process filtration, a sand filter (Figure 4) was designed to treat the residual suspended solids resulted from the coagulation – flocculation process (jar test).

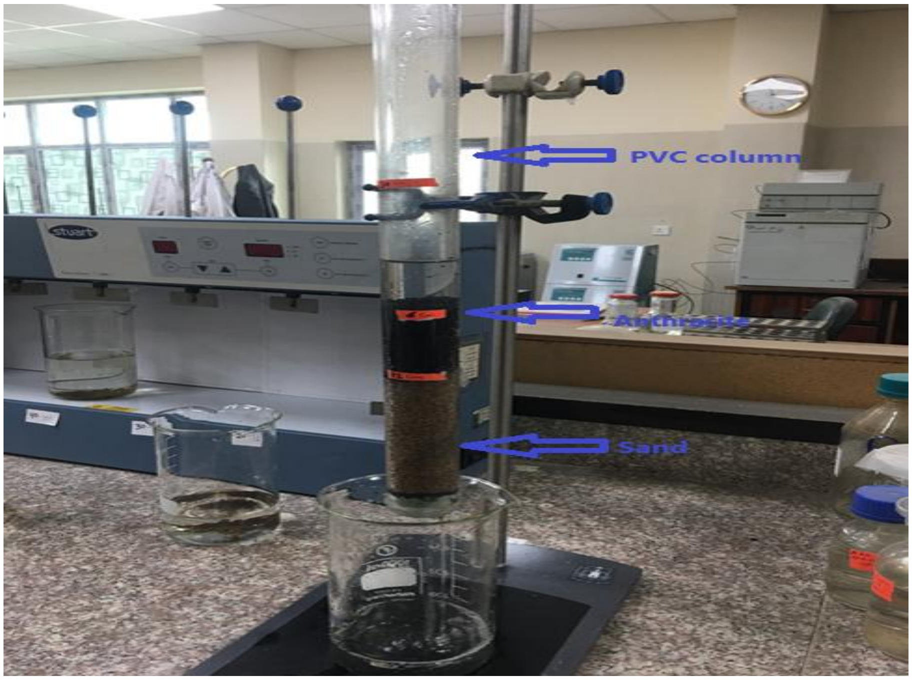

Figure (4): Laboratory sand filter designed by research team

The running speed of the filter is designed at the lowest speed within the parameters of fast sand filters, which is equivalent to 100 m/d (4.2m/hr.). To determine the flow rate of filtration, the dimensions of the filter were 24 cm (height) and 5cm (diameter). Assumption velocity of filtration is 5 m/hr. The surface area was calculated as 0.00196 m^2. The flow rate(Q) was calculated by multiplying the velocity by surface area and it was 9.8 L/hr. ≅ 10 L/hr. Various concentrations of sodium sulfite solution (10-100 mg/L) (Rashid & Khadom, 2020) were used in this work to decrease the concentration of dissolved oxygen.

3. Results and Discussion

The sample of produced water (PW) was analyzed and the results were explained in Table (2).

Table (2): Specifications of raw PW (EBOF)

Parameter	Units	Result
pH	…………….	6.71
TSS	mg/l	164
Turbidity	NTU	45
Conductivity	µs/cm	27510
Oil & Grease	mg/l	74
Sulfide (S^{-2})	mg/l	684
TDS	mg/l	22745

The table showed an acceptable value of pH (6.71) compared with the required of acidity parameter of water for injection application, the required pH for reinjection varies from 6.5 to 7.5 as mentioned in Table (1). A pH value of the raw PW can be changed during the treatment process due to the using of chemicals but no high diffraction of pH value because of high TDS concentration of water which represent as a buffer system. A little oil and grease concentration(74mg/L) make it easy to decrease to less than 5mg/L (Table 1) via adsorbing and settling at coagulation -flocculation process where the oil is adsorbed on the coagulant and flocculant agents making it unrecoverable (Pintor et al., 2016). High concentration of sulfide (684 mg/L) result in corrosion problems for oil production facilities(Popoola et al., 2013). Corrosion inhibitors and hydrogen sulfide scavengers are usually added to the water before injection to the field to reduce the influence of the sulfide corrosivity effect(Bediako et al., 2023) . TSS and turbidity concentrations are more than the water injection specifications so a combination of flocculation and filtration technique would be used. Injection of water with these values may causes serious problem in oil field with long term oil production. Using of PAC, ALM, and FCH showed good results in turbidity reduction of the raw sample. The optimum doses of theses coagulants were 20 ,40, and 50 mg/L to get the turbidity values of 0.34 ,0.79, and 1.26 NTU for PAC, ALM, and FCH respectively. The Figures (5,6, 7) explains the relations between turbidity and TSS via using PAC, ALM, and FCH. The removal efficiencies (%) of turbidity via PAC, ALM, and FCH were 98.8, 98.2, and 97.2 respectively. The settling velocity of the suspended solids after adding the coagulants and flocculants was 20-50mm/min. This velocity of settling is ranked as a good sedimentation circumstance. Using of PAC is more efficient and feasible than the other coagulants. The best result for removing the turbidity via PAC may be due to polymer society of the molecule which have additional positive charge that more affective in destabilizing the colloidal system of the turbid produced water. On the other hand, a high reduction in TSS concentration (TSS of raw PW is 164 mg/L) of the tested water samples by the jar test process that could not be detected by using MD100 measuring device manufactured by LOVIBOND.

As expected, the pH values of water samples were not affected after a combined adding of the coagulant and flocculant. pH of 6.99, 6.74, and 6.5 have resulted when using optimum doses of PAC, ALM, and FCH respectively compared to the pH value (6.71) of the raw PW Table (2) that is justifies using PW water for reinjection safely.

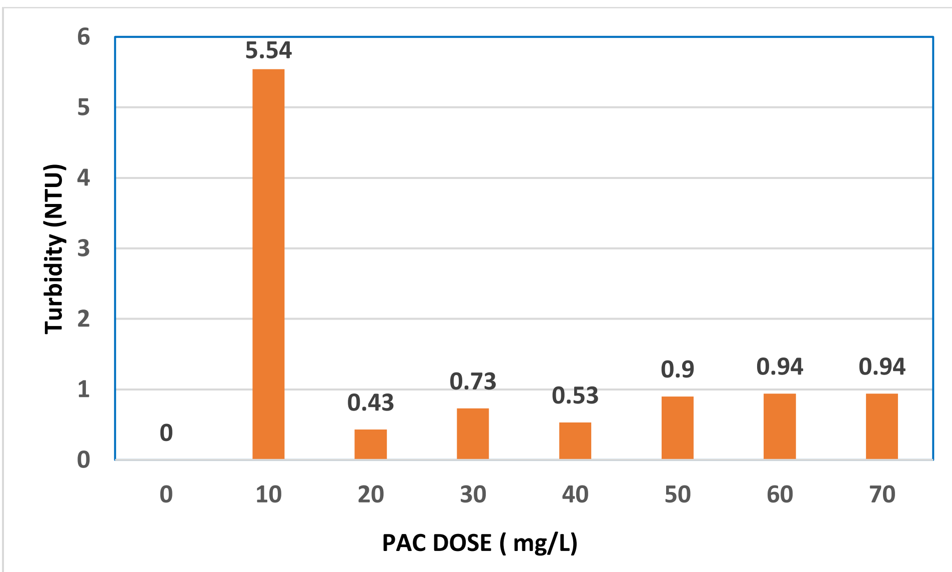

Figure (5): PAC dose vs Turbidity

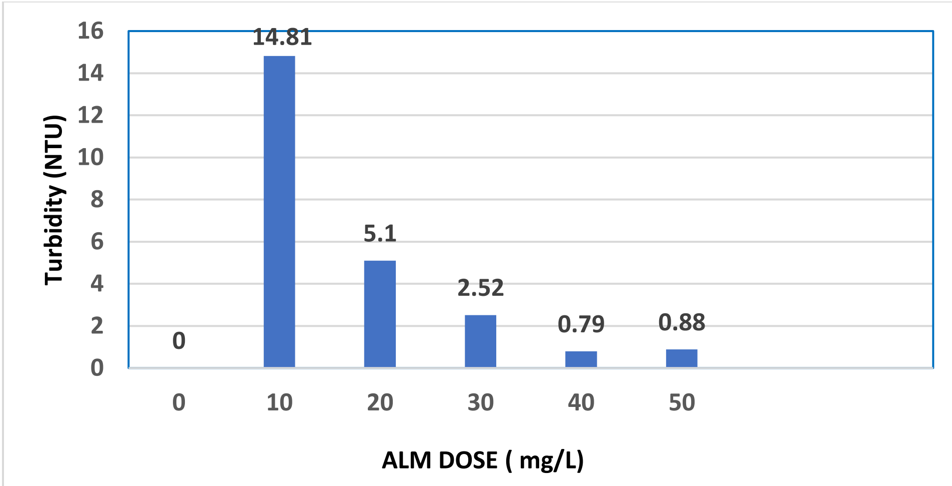

Figure (6): ALM Dose vs Turbidity

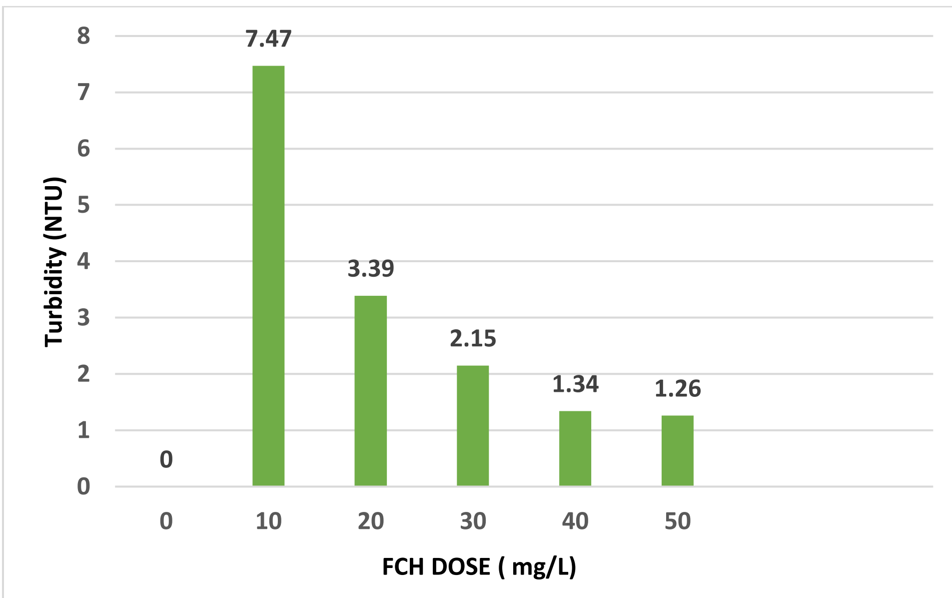

Figure (7): FCH Dose vs Turbidity

To simulate a real filtration process in water treatment plants, the water treated using PAC was passed on a laboratory designed filter to get rid of the residual TSS. A fast filtration process was used. Anthracite and sand that put in the reactor showed a great efficiency of filtration. Table (3) demonstrates the specifications of PW after sand filtration.

Table (3): Specifications of sand filterated water

Parameter	Unit	Result
pH	…………….	7.4
TSS	mg/l	Not Detected
Turbidity	NTU	0.15
Conductivity	µs/cm	22000
Oil & Grease	mg/l	Trace
Sulfide	mg/l	729.6
TDS	mg/l	18189.4

This table shows the minimum limits of the turbidity, TSS, and oil grease which represents typical circumstances for safely water injection for SOR. Injection of water in the petroleum field with high DO concentration causes corrosion to the Oil production supplies and equipment (Kuraimid, Kh, Ahmed, Walled, Saffa, 2021). The dissolved oxygen of PW was 2.14 mg/ L. Using of sodium sulfite to treat the DO concentration was used successfully leading to lower the concentration of DO. The optimum dose of the sodium sulfite used was 100mg/L to reduce DO to 0.7 mg/L as explained in Figure (8). Although 0.7mg/L concentration of DO is not allowed for water reinjection application in petroleum field production companies (Bondar et al., 2018), it would be decreasing the concentration of DO to the minimum levels that could be removed by other DO striping technologies such as using deaerator. (Butler et al., 1994).

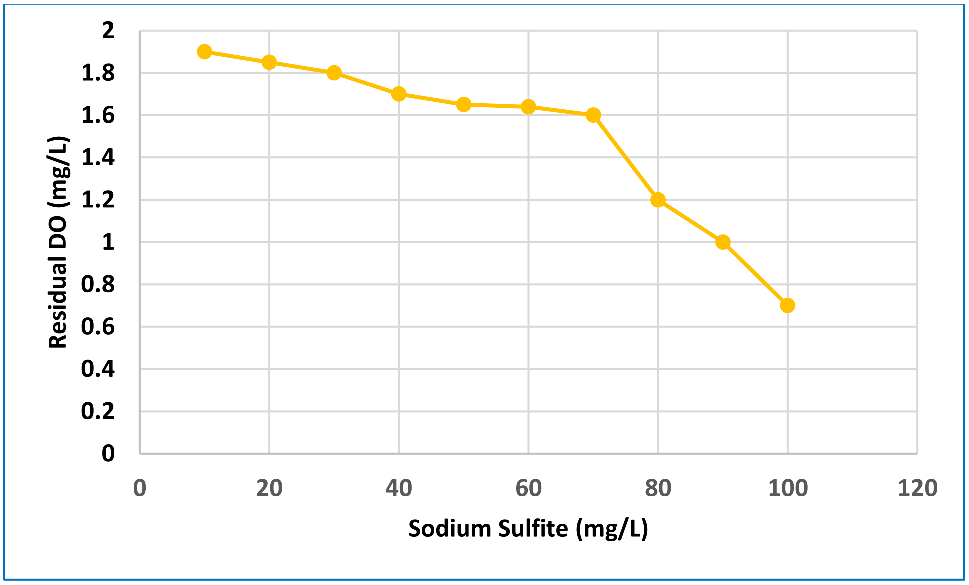

Figure (8): Sodium sulfite Dose vs Residual DO

4. Conclusions

The methodology employed in this study effectively treated key parameters of produced water from the East Baghdad Oil Field, including pH, Total Suspended Solids (TSS), turbidity, and dissolved oxygen (DO), demonstrating its potential for successful reinjection and enhanced oil recovery. The pH of the treated water ranged from 6.71 after the coagulation-flocculation phase to 7.4 after final treatment, falling within the recommended range of 6.5-7.5 for safe reinjection. Among the coagulants tested, PAC (polyaluminum chloride) exhibited the highest efficiency, reducing turbidity from 45 NTU to 0.43 NTU at an optimal dose of 20 mg/L. Dissolved oxygen was effectively removed using sodium sulfite, achieving a concentration of 0.7 mg/L. However, as these experiments were conducted in an open system, a closed system is recommended for full-scale operations to further minimize dissolved oxygen levels to get the best result of dissolved oxygen concentration. The findings of this study demonstrate the feasibility of treating produced water from the East Baghdad Oil Field for potential reinjection. However, further research and pilot-scale testing are essential to optimize treatment processes and ensure successful and sustainable reinjection operations is recommended to use. One other point should be taken inconsideration, reinjection may be limited by insufficient water volume. If mixing with other water sources is necessary, a thorough compatibility study must be conducted to determine the optimal water type and mixing ratio to prevent operational problems and well damage.

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