Investigating the effective treatment of oilfield-produced water using various materials

تقييم كفاءة مواد مختلفة في معالجة المياه المصاحبة لإنتاج النفط

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ABSTRACT

The high concentration of organic, inorganic, and hazardous substances in produced water from oil and gas operations is a significant environmental problem. Nowadays, the petroleum business relies heavily on its treatment. The physical treatment approach utilizing adsorption was the main focus of this investigation. Samples of produced water were gathered from oil fields. The tests were conducted at room temperature. Adsorption was successful in drastically lowering the oil concentration. The produced water from the AA field had to be treated as the first stage. Various sustainable and chemical materials were employed. Before and after filtering, the oil content was 306.3 mg/L and 30.7 mg/L, respectively (indicating that filtration alone removed ~90%). The oil removal efficiency of activated carbon at different concentrations (0.01, 0.02, 0.03, 0.05, and 0.1 grams) was evaluated relative to the post-filtration concentration as 51.8%, 79.4%, 94.7%, 100%, and 100%, respectively. 100% elimination efficiency was attained by combining 0.03 g of activated carbon with 0.005 g of the nanomaterial Fe3O4 (total mass 0.035 g). At a concentration of 0.2 grams, additional materials such as graphene, sawdust, banana peel powder, and orange peel powder were also utilized, all of which achieved 100% removal efficiency. The BB field was tested in the second step. The oil concentration was 25 mg/L before filtration, and it was reduced to 1.1 mg/L after filtration. Activated carbon (0.02g) and a mixture of activated carbon (0.02g) with the nanomaterial Fe3O4 (0.005 g) were used; the oil removal efficiency was 54.5% and 100%, respectively. Additionally, heavy metals, specifically iron, were measured using Atomic Absorption Spectroscopy (AAS); the initial concentration was 720 mg/L, which was

reduced to < Detection Limit < 0.05 mg/L after treatment with 1 g of activated carbon at optimized pH and contact time. The trials' findings demonstrated that the combination of activated carbon and the nanomaterial Fe3O4 at a concentration of 0.005 g was the most effective material for removing oil from produced water, achieving the highest removal efficiency (100%) in both the AA and BB fields at the lowest total dosage

الملخص .

تُعدّ التركيزات العالية من المواد العضوية وغير العضوية والخطرة في المياه المُنتجة من عمليات النفط والغاز مشكلة بيئية كبيرة؛ لذا يعتمد قطاع النفط حالياً بشكل كبير على معالجة هذه المياه. ركّز هذا البحث على أسلوب المعالجة الفيزيائية باستخدام تقنية الامتزاز .جُمعت عينات من المياه المُنتجة من حقول نفطية، وأُجريت الاختبارات في درجة حرارة الغرفة. أثبتت عملية الامتزاز فاعليتها في خفض تركيز النفط بشكل كبير. في المرحلة الأولى، عولجت المياه المُنتجة من الحقل "AA" باستخدام مواد متنوعة، منها مواد مستدامة وأخرى كيميائية. بلغ تركيز النفط قبل الترشيح 306.3 ملجم/لتر، وانخفض إلى 30.7 ملجم/لتر بعد الترشيح (مما يشير إلى أن عملية الترشيح وحدها أزالت حوالي 90% من النفط). كما تم تقييم كفاءة إزالة النفط باستخدام الكربون النشط بتركيزات مختلفة (0.01، 0.02، 0.03، 0.05، و0.1 جرام)؛ حيث بلغت كفاءة الإزالة -بالنسبة للتركيز المتبقي بعد الترشيح- 51.8%، 79.4%، 94.7%، 100%، و100% على التوالي. وقد تحققت كفاءة إزالة بنسبة 100% عند دمج 0.03 جرام من الكربون النشط مع 0.005 جرام من المادة النانوية "Fe3O4" (بكتلة إجمالية قدرها 0.035 جرام). كما استُخدمت مواد أخرى بتركيز 0.2 جرام، شملت الجرافين، ونشارة الخشب، ومسحوق قشور الموز، ومسحوق قشور البرتقال، وحققت جميعها كفاءة إزالة بلغت 100%. وفي المرحلة الثانية، أُجريت الاختبارات على عينات من الحقل"BB" ؛ حيث بلغ تركيز النفط 25 ملجم/لتر قبل الترشيح، وانخفض إلى 1.1 ملجم/لتر بعده. وعند استخدام الكربون النشط (0.02 جرام) ومزيج من الكربون النشط (0.02 جرام) مع المادة النانوية "Fe3O4" (0.005 جرام)، بلغت كفاءة إزالة النفط 54.5% و100% على التوالي. بالإضافة إلى ذلك، تم قياس تركيزات المعادن الثقيلة -وتحديداً الحديد- باستخدام تقنية مطيافية الامتصاص الذري .(AAS) بلغ التركيز الأولي 720 ملجم/لتر، وانخفض إلى أقل من حد الكشف (< 0.05 ملجم/لتر) بعد المعالجة باستخدام 1 جرام من الكربون المنشط، مع ضبط الأس الهيدروجيني (pH) وزمن التلامس عند القيم المثلى. وأظهرت نتائج التجارب أن استخدام مزيج من الكربون المنشط والمادة النانوية (Fe3O4) بتركيز 0.005 جرام كان الأكثر فعالية في إزالة الزيت من المياه المصاحبة للإنتاج؛ حيث حقق أعلى كفاءة إزالة (100%) في كل من حقلي "AA" و "BB"بأقل جرعة إجمالية ممكنة.

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الكلمات المفتاحية: المياه المصاحبة للإنتاج، تحسين معالجة المياه، عملية الامتزاز، إزالة الزيت

Introduction

In subsurface formations, naturally occurring rocks are generally permeated with fluids such as water, oil or gas (or some combination of these fluids). It is believed that the rock in most oil- bearing formations was completely saturated with the water prior to the invasion and trapping of petroleum. The less dense hydrocarbons migrated to trap locations, displacing some of the water formation in becoming hydrocarbon reservoirs. The reservoir rocks normally contain both petroleum hydrocarbons (liquid & gas) and water [1].

In the past decades, the oil and gas industry has accompanied by consuming a massive amount of water [2], these activities generate large volumes of liquid waste, known as oilfield produced water (PW) [3]. Produced water is an inextricable part of the hydrocarbon recovery process [4], and its production is expected to increase due to the growing demand for oil and aging oilfields [5] . PW is generally classified as oilfield PW, natural gas PW and coal bed methane (CBM) PW depending on its origin [6].

The volume of OPW and its evolution over time differ between oilfields and gas fields as oil reservoirs usually contain larger volumes of water than gas reservoirs as gas has a higher compressibility and sorption capacity than oil, and also because gas is stored in less porous reservoirs. The volume of Products water (PW) and wells' behavior are also very heterogeneous between the types of production; conventional oil and gas wells typically show a gradual increase of water production while hydrocarbon production is decreasing. In contrast, in unconventional Oil and gas production, the volume of PW tends to be correlated with the volume of hydrocarbons extracted [7]. But The amount of water produced from most Coal-Bed Methane CBM wells is relatively high compared to conventional natural gas wells because coal beds contain many fractures and pores that can contain and transmit large volumes of water. In some areas, coal beds may function as regional or local aquifers and important sources for ground water [8].

The produced water is part of natural formation water existing beneath or within the oil/gas reservoir. Thus, the constituents of PW are based on natural geological formation [9]. produced water may have complex composition including: organic or inorganic ingredients like: salts, metals, dispersed oil, phenols, organic acids,

dissolved hydrocarbons [10] , and often also chemicals added to the production system to aid the extraction processes or to protect against biofouling and corrosion [11].

Over time, the proportion of water in production increases while the proportion of hydrocarbons decreases, making the management of PW increasingly complex. Improper disposal of PW can lead to soil and groundwater contamination, negatively impacting agriculture, irrigation, and livestock [12] . For petroleum fields, the produced water in most cases is discarded into evaporation ponds outside the fields and this causes serious environmental problems for air, soil, and ground water [1].

On the other hand, because large volumes of produced water are being generated, many countries with oilfields, which are also generally water stressed countries, are increasingly focusing on efforts to find efficient and cost-effective treatment methods to remove pollutants as a way to supplement their limited fresh water resources. Reuse and recycling of produced water include underground injection to increase oil production [3]. Treat the produced water to meet the quality required to use it for drilling, stimulation, and workover operations. Consume in beneficial use In some cases, significant treatment of produced water is required to meet the quality required for beneficial uses such as irrigation, rangeland restoration, cattle and animal consumption, and drinking water for private use or in public water systems.

Produced water handling practices must also be environmentally protective. Treatment of produced water has been attempted and is proven to be an effective option for produced water handling. Studies conducted to identify, verify and compile existing and newly developed techniques demonstrate the economic benefits of produced water treatment. Treating oilfield water can help facilitate additional water management options for operators such as beneficial uses that in the short and long term can potentially provide certain community and economic advantages. Treated produced water has the potential to be a valuable product rather than a waste. The treatment of produced water is a necessity before the majority of the conventional produced waters can be applied to other uses [13] Various conventional and advanced water treatment technologies have been applied to treat produced water. Each technology has its advantages and disadvantages with respect to treatment efficiency, requirements for chemicals, equipment and energy, environmental footprint, and cost. Evaluation and selection of the best technologies available for treatment of produced water from a particular source must

take into consideration the types of contaminants to be removed, the levels of total dissolved solids (TDS), and the goal of treatment required for potential end use [14].

Conventional methods such as adsorption, coagulation, membrane processes, dissolved air flotation, and biological processes have been performed to treat produced water from oil fields. [15]

Sources of Produced Water

The oil and gas (O&G) industry produces large volumes of water During the extraction, processing, and refining of hydrocarbons. The water that is brought to the surface with hydrocarbons during extraction is termed 'produced water' (PW); this often comprises both formation water (which naturally occurs in significant quantities in the reservoir with the hydrocarbons) and water that has been withdrawn From another source, injected into the O&G reservoir, and returns to the surface with the hydrocarbons (e.g. water injected for enhanced oil recovery and for hydraulic fracturing).[7]

Naturally occurring rocks, in subsurface formations are generally permeated by different underground fluids such as oil, gas, and saline water. Before trapping hydrocarbon compounds in rocks, they were saturated with saline water. Hydrocarbons with lower density migrated to trap locations and displaced some of the saline water from the formation. The last category is called "connate water" or "formation water" and becomes produced water when saline water mixed with hydrocarbons comes to the surface. [3]

In oil and gas production activities, additional water is injected into the reservoir to sustain the pressure and achieve greater recovery levels. Both formation water and injected water are produced along with hydrocarbon mixture. At the surface, processes are used to separate hydrocarbons from the produced fluid or produced water.[17]

Water is present in every stage of the oilfield life cycle, from the exploration, through field development, production, and abandonment. The volume of produced water is not constant during a life cycle of the oilfield, because the water-oil ratio (WOR) increases during production. The main causes of presence of produced water during the oil production are: [18]

•Tubing, casing or packer leak,

•Channel flow behind casing,

•Raise of oil-water contact,

•High permeability layer without crossflow,

•Fractures or fissures between injectors and producers,

•Fractures or fissures from a water layer,

•Water coning or cusping,

•Poor areal sweep,

•Gravity-segregated layer,

•High permeability layer with crossflow.[18]

Produced Water Characteristics

Produced water characteristics Its composition varies from simple to complex i.e. it's not a single component, ″it is a combination of dissolved and particulate organic and inorganic chemicals".

The wastewater properties differ depending on many parameters like the geographical site of the field, the depth and age of geological formation, the method of extraction, hydrocarbon-bearing formation geochemistry, type of conducted hydrocarbon, in addition to the chemical components of the reservoir.[18]

The major components of produced water are:

Dissolved organic compounds OPW

generally, contains a mixture of phenol, benzene, xylenes, toluene, and ethylbenzene. These aromatic compounds have been classified as high priority chemicals.

The majority of the hydrocarbons do not dissolve in the water, so most of the oil is dispersed in water as an emulsion, or clearly separated into two phases. Therefore O&G in PW can be in the form of free, dispersed and emulsified oil.

The water-soluble organic compounds in PW are usually polar constituents with a low number of carbons, like organic acids such as formic and propionic. pH, temperature and pressure (in the reservoir or during extraction) increase soluble organics in PW.[6]

Dissolved inorganic compounds OPW

contains many dissolved inorganic compounds from formation minerals, which are present as cations and anions. These compounds contribute to the increase in conductivity, salinity and scale formation. The most abundant inorganic compounds in OPW include salts of barium, calcium, magnesium, sodium, potassium, and chloride. OPW also contains trace amounts of different heavy metals.[6].

Produced solids Natural and artificial solid in OPW.

Are two types of solids present in OPW generated during oil production. Natural solids are reservoir materials flowing to the surface, such as plankton, silt, algae, clay, sediment and sand. Artificial solids are introduced from external intervention, and include wax, proppant, corrosion debris, gravel pack particles, drill mud, and cement fines. Blockage caused by these solids reduces well flow rate leading to the decrease in production output.[21]

Dissolved gases Significant amounts of dissolved gases are contained in OPW.

Commonly found dissolved gases includes carbon dioxide, nitrogen, oxygen, and hydrogen sulphide. These gases can be toxic and corrosive when present in large quantities.[6]

Conductivity, salinity and total dissolved solids (TDS)

The conductivity of produced water can vary widely as it was found that the conductivity of produced water from natural gas ranged from 4200 to 180,000 uS/cm . In another research, the conductivity was found to be in a range of 136,000-586,000 uS/cm . The salinity of produced water ranges from few parts per thousand (%0) to 300%0 (saturated brine) which is much higher than the salt concentration of seawater which is in the range of 32-36‰ and that is why produced water is generally denser than seawater. Higher salinity results due to the presence of dissolved chloride and sodium mainly as the con- cent rations of calcium, magnesium and potassium are usually lower., TDS was in the range of 370-1940 mg/L due to the increased concentrations of both sodium and bicarbonate [2].

Produced Water Treatment Methods

Since, produced water contains several different contaminants with varying concentrations, therefore, numerous treatment technologies have been proposed for produced water treatment. The wide variety of

produced water treatment methods have been reported previously. The treatment system usually requires a series of individual unit processes for contaminants removal that might not be removed through a single process. Treatment of produced water can help in facilitating additional options for water management including its reuse for agricultural and industrial purposes., the treatment of produced water should be able to remove dispersed and free oil and grease, soluble organics, suspended solids and dissolved gases, naturally occurring radioactive materials, salts and microorganisms. As a result, it is challenging to choose the type of treatment system suitable to remove most of the contaminants from produced water. Generally, the cheapest method is the most preferable one and the cost of the produced water treatment mainly depends on influent quality, electricity price, plant's capacity, as well as the intended quality of the effluent [2].

Chemical Treatment

Chemical Precipitation

Suspended and colloidal constituents from the produced water can be removed by coagulants and flocculants. An inorganic mixed metal is a poly-nuclear polymer, FMA (Fe, Mg, and Al) is with properties of coagulation scale inhibition and deoiling. This can remove suspended particles from produced water with concentration levels of 50–400mg/L. Suspended solids and oil can be removed up to approximately 92% and 97%, respectively [22]. Similarly, heavy metals can also be removed by using spills orb, lime and calcite. The suspended solid removal efficiency of lime is higher than others and it is an economical chemical as well. Several coagulants like modified hot lime, Spills orb, calcite and ferric ions were used as coagulant to treat produced water. The disadvantages of this process are its ineffectiveness for dissolved components and the increased concentration of metals in the sludge formed. [23] Treatment of produced water from oil and gas fields to remove arsenic, hydrocarbons and mercury has been done with flocculants, oxidant and ferric ions.

Chemical Oxidation

Chemical oxidation is an established and reliable technology for the removal of color, dour, COD, BOD, organics and some inorganic compounds from produced water. Chemical oxidation treatment depends on oxidation/reduction reactions occurring together in produced water because free electrons cannot exist in

solution [24]. Oxidants commonly used include ozone, peroxide, permanganate, oxygen and chlorine. The oxidant mixes with contaminants and causes them to break down.

Refractory chemicals present in produce water are decomposed by a process of chemical oxidation which uses a catalyst, oxidant, and irradiation [25]. The oxidation rate of this technology depends on chemical dose, type of the oxidant used, raw water quality and contact time between oxidants and water. Chemical cost during this process may be high. Energy consumption accounts for ~18% of the total cost of operations and maintenance. It requires minimal equipment and has a life expectancy of 10 years or greater and solid separation post-treatment may be employed to remove oxidized particles [26].

Demulsifies

In the alkali/surfactant/polymer (ASP), flooding process large quantities of alkali, surfactants, and polymer chemicals are used. During the production process, residual chemicals enter to produce water. Surfactants are mainly responsible for the stability of oil droplets, reducing oil–water interfacial tension, and zeta potential on the surfaces of the oil droplets. The 'skin' surrounding the tiny droplets in the oil–water emulsion prevents the water droplets from uniting and the emulsion remains stable. Demulsifies are surface-active agents that are effective in disrupting the effects of natural emulsifiers present in the oil. In most crude oils, solids such as iron sulfides, silts, clay, drilling mud, paraffin, etc. complicate the demulsification process.

Ozonolysis

Ozonation was studied as a treatment option to remove polycyclic aromatic hydrocarbons (PAHs) from offshore PW using experimental and modeling approaches. Ozonation demonstrated its effectiveness for the removal of PAHs. Ozonolysis was proposed [22] for the treatment of oil-well-produced water by the decomposition of dissolved hydrocarbons through ozone. The use of ozone as a powerful oxidizing reagent has been applied to the treatment of water samples [21][22]. In addition to its high production cost, ozone has a relatively low solubility and stability in water and selectively reacts with organic compounds at acidic pH. Furthermore, ozone reacts slowly with certain organic substances such as inactivated aromatics or saturated carboxylic acids, and in many cases does not completely mineralize these organic compounds [26][25]. These disadvantages make the application of ozone alone to treat polluted water economically undesirable and is the reason why ozonation

processes are sometimes modified by the addition of catalysts to the oxidation medium to improve oxidation efficiency. One of these modifications employs photoactivated semiconductor (as photocatalysts) in combination with ozone, resulting in a new advanced oxidation method called photocatalytic ozonation [11]. This combination, and the resulting synergistic effects, is thought to be a promising technique for the decomposition of refractory microorganisms and organic compounds in water. [15] showed that among six different advanced oxidation processes, photocatalytic ozonation was the most efficient for complete mineralization of 4-chloronitrobenzene.

Electrochemical Process

Electrochemical water treatment systems utilize electricity to induce the removal of dissolved contaminants in the water. The introduction of a negatively charged electrode, or cathode, into the water will cause positively charged cations to move toward its Electrochemical treatment is very efficient and reduces process times. In a laboratory experimental setup of pilot-scale plant that included double anodes with active metal, graphite, and iron as cathode and a noble metal content crystal with a large surface, the COD and BOD of oilfield produced water could be reduced by over 90% in 6 min. In these processes, produced Mn2+ ions oxidized and coagulated organic pollutants including bacteria [24].

Photocatalytic Treatment

Photo catalytic decomposition of water on TiO2 electrodes is a method used for pollutant removal. The general process for organic-pollutant treatment by photocatalytic method is as follows:

$$organic\ pollutant + O_2\ CO_2 + H_2O + mineral\ acids$$

For oilfield-produced water treatment, a photo catalytic reaction was performed in a reactor with 60 mL clarified produced water at a high pH. The required amount of photcatalyst-TiO2 was added. The suspension was heated up to 298 K and illuminated using mercury lamp of 250 W at a high pressure. As a result, the toxicity of the produced water was decreased [22].

Physical Treatment

Filtration

Filtration is relatively simple technique used in water and waste water treatment process, which is based on the use of porous filter media to allow only the water but not the impurities to pass through it. There are various porous materials that can be used as filter media, such as sand, crushed stone, and activated carbon. However, the widely used material is sand due to its availability, low cost and efficiency.

Filter beds are mainly composed of fine grains with 0.15-0.35 mm diameter range and 1 m depth before starting the filtration process. As the filtration proceeds, the higher part of the treatment system will contain the colloidal and suspended particles coming from the untreated water, and as these particles build up they will clog the system and reduce its efficiency. Therefore, it is necessary to scrap off the top layer of the sand which is full of impurities to remove the clogging materials. [4]

❖ Sand filters

❖ Adewumi et al. [3] proposed a three-step pretreatment before sand filtering for removing metals from produced water. The system consisted of the following:

• pH adjustment; to initiate oxidation reaction,

• Aeration unit: to increase oxygen concentration for reaction,

• Solid separation unit: sufficient retention time for settling of precipitated solids,

• Sand filtration: removing fine solids that could not settle.

Results of different runs by the system showed that more than 90% iron could be removed.[3]

Flotation

In this method, fine gas bubbles utilized for the separation of suspended particles that cannot be removed by sedimentation. This process is done by injecting gas into the water to be treated, then both suspended particulates and oil droplets will attach to the air bubbles, and then they will rise to the surface leading to the formation of foam that is removed by skimming. This process can be done using air, nitrogen or other types of inert gases. The technique can be used for the removal of volatile organics, oil and grease from produced water. The efficiency of the process mainly depends on the contaminants to be removed, density differences of liquids, temperature, and the size of the oil droplet. Flotation process does not work ideally with high temperature feed streams; however, it works well under cold temperature and can be used for the treatment of produced water.

Particles with 25 µm size can be removed by dissolved air flotation process. The percentage oil removal of up to 93% has been obtained using flotation process.[2]

Cyclones

A cyclone, uses centrifugal acceleration to mechanically reduce, or increase, depending on the objectives of the process, the concentration of a dispersed phase (aggregates, particles, droplets, etc.) within a dispersant media. The dispersed phase elements size can range of 5 to 15 µm, depending on the design of the cyclone. its three-phase design, it was able to de-sand and de-oil the treated effluent. A double cone air sparged hydro cyclone (DCASH) was designed for PW treatment. This system used air bubbles to enhance removal efficiency of oil droplets [6].

Hydro cyclones

Hydro cyclones use physical method to separate solids from liquids based on the density of the solids to be separated. They are made from metals, plastics or ceramic, and usually have a cylindrical top and a conical base with no moving parts (Figure 3). The performance of the hydro cyclone is determined by the angle of its conical section. Hydro cyclones can remove particles in

the range of 5-15 µm and have been widely used for the treatment of produced water. Nearly 8 million barrels per day of produced water can be treated with hydro cyclones. They are used in combination with other technologies as a pre-treatment process. They have a long lifespan and do t require chemical use or pre-treatment of feed water. A major disadvantage of this technology is the generation of large slurry of concentrated solid waste.[4]

Adsorption

Adsorption is one of the most effective methods for treating oil-produced water (OPW) and removing hazardous pollutants such as heavy metals and organic compounds. This technique works by attracting contaminant molecules to the surface of adsorbent materials, significantly reducing their presence in water. Factors like temperature and pH play a crucial role in adsorption efficiency, as changes in these conditions can either enhance or weaken the material's ability to capture pollutants. [17]

EXPERIMENTAL WORK

the experimental methods used to assess how well a variety of materials remove contaminants from produced water related to oil extraction activities.

Due to its ease of use and effectiveness in eliminating a variety of contaminants, adsorption techniques were used in this study as an efficient and eco-friendly treatment strategy. Based on their availability, physical and chemical characteristics, and recorded outcomes in earlier research, a variety of novel and natural materials were chosen, such as graphene, sawdust, banana and orange peel powder, activated carbon, and nano-iron oxide. To guarantee an exact comparison of material efficiency, batch adsorption technology was employed in every experiment under consistent operating circumstances.

Materials Used:

A range of modern materials of sustainable or nano-based origin have been used to treat oil-related produced water, including: 1. produced water 2. Activated Carbon 3. Sawdust 4. Banana Peel Powder 5. Orange Peel Powder 6. Magnetic nano particles Fe3O4 7. Graphene

Devices and equipment:

1. Beakers – 1 L and 500 mL 2. Erlenmeyer Flasks – 1 L and 500 mL 3. Medium- Filtration funnel

4. filter paper.

5. Opaque Sample Bottles – 25 mL ,50 mL , 100 mL , 200 ml

6 Magnetic Stirrer

7. Small Thermometer

8. Magnetic Stir Bar

Iron Oxide (Fe_3O_4) Nanoparticles

This sample is a solid magnetic iron oxide nano powder, characterized by high density and chemical stability. It was selected for its magnetic properties and nanoscale structure, which are beneficial in advanced environmental applications.

Physical State: Solid nano powder, odorless

Relative Density: 4.95 g/cm³

Lateral Size: 25 nm

Melting Point: 1538°C

Analytical Methods & Measurement Instruments:

Heavy Metals (Iron): Measured using Atomic Absorption Spectroscopy (AAS) with a method detection limit of 0.05 mg/L.

Oil Concentration: Measured using Fourier Transform Infrared (FTIR) spectroscopy according to standard method EPA 418.1, with a method detection limit (MDL) of 0.1 mg/L.

Activated Carbon

Physical State: Solid black fine powder, odorless

True Density: 1.8–2.1 g/cm³

Particle Size: ≤150 μm

Apparent Density: 0.45–0.55 g/cm³

Specific Surface Area: >1000 m²/g

This high-surface-area activated carbon powder is ideal for adsorption-based water treatment, offering high efficiency in oil removal and excellent stability across various conditions.

Graphene

Commercial Name: Nanoscale Graphene Nanosheets (10 nm) with 99% Purity

Thickness: 10 nm

Lateral Size: 10 μm

Appearance: Grey-black powder

Apparent Density: 0.08–0.12 g/cm³

Specific Surface Area: 100 m²/g

Technical Features: Excellent electrical and thermal conductivity, high chemical stability, and mechanical strength

Graphene nanosheets were selected due to their exceptional mechanical, electrical, and thermal performance. Their high purity and nanoscale dimensions make them particularly suitable for use in high-efficiency water treatment systems.

Hotplate Magnetic Stirrer

Voltage: 220V / 50Hz

Power Consumption: 500W / 2.5A

Operating Mechanism: Equipped with two control knobs: One for adjusting the heating (HEAT) ,One for adjusting the stirring speed (STIR)

Includes indicator LED lights for both heating and stirring status.

Applications: Used in chemical and biological laboratories for simultaneous heating and magnetic stirring of liquids.

Qualitative Filter Paper

Diameter: 15 cm

Specifications:

- Pore size: 10–25 µm.

- Filtration speed: 30–100 seconds/100 ml .

Banana and orange peels

peels were collected and dried thoroughly in a clean place away from dust and moisture. After ensuring complete dryness, they were ground using an electric grinder to a fine powder for use in the experiments.

Preparation and Treatment Method:

All batch adsorption experiments were conducted in triplicate (n = 3) at controlled room temperature (25 ± 2 °C), and the reported results represent the mean values with a relative standard deviation (RSD) of less than 3%.

First Step:

Produced water samples were obtained from the AA field produce water, and 200 ml of water was used for each experiment.

Material preparation: Each material was tested separately. According to the following steps,

1.The produced water was filtered using filter paper to remove suspended impurities and a portion of the hydrocarbons.

2.The filtered water was placed in a beaker of suitable capacity and placed on a magnetic stirrer for stirring.

3.The weight measurement of the materials: The quantities of the materials used ranged as follows: Graphene is 0.2 g, Sawdust is 0.2 g, activated carbon is 0.01 g,0.02g, 0.03 g, 0.05 g,0.1g. Banana peel powder is 0.2 g, orange peel powder is 0.2 g.

4.The treated material was gradually added while continuing to stir to ensure homogeneous distribution.

5.Stirring continued for 150 minutes at room temperature.

6.The samples were left for a full hour after stirring to allow the added materials to precipitate.

7.After the settling period, the water was filtered again using filter paper to separate the solids from the treated water. These steps were repeated for each substance and each concentration separately, keeping other experimental conditions constant to ensure accurate and comparable results.

second Step:

Produced water samples were obtained from the BB field, and 200 ml of water was used for each experiment.

Material: Activated Carbon (0.02g,1g), Magnetic nano particles Fe3O4 (0.005g)

RESULTS AND DISCUSSION

Results before filtration

The experimental results demonstrate a significant potential for using low-cost and sustainable materials for the physical treatment of produced water from oilfields. The initial oil content in AA field produce water was remarkably high (306 mg/L), indicating severe contamination, while the BB field sample had a concentration (25 mg/L). This variation highlights the influence of geological and operational differences between fields.

First Step – AA Field Produced Water

Oil content before and after filtration (AA Field)

- Before filtration: 306.3 mg/L
- After filtration: 30.7 mg/L

- Filtration removal efficiency: 90%

Table **(1)** the Oil concentration (mg/L) before and after filtration

sample	Oil content percentage		
	Before filtration process mg/l	After filtration process mg/l	Removal efficiency%
Produced water	306.3	30.7	90

After filtering, the concentration dropped from 306 mg/L to 30.7 mg/L, resulting in a removal effectiveness of about 90%. The filter paper's comparatively small pore size is responsible for this notable decrease. Effective physical separation resulted from the oil droplets' relatively large size, which prevented many of them from passing through the filter's pores.

Table 2: Oil content concentration for produced water after treatment with different materials calculated relative to post-filtration concentration of 30.7 mg/L

Materials used	Concentrations g	Oil content mg/l	Removal efficiency%
Activated Carbon	0.01	14.8	51.8
Activated Carbon	0.02	6.3	79.4
Activated Carbon	0.03	1.6	94.7
Activated Carbon	0.05	< Detection Limit	100
Activated Carbon	0.1	< Detection Limit	100
Fe3O4 (0.005g) + Activated Carbon	0.03	< Detection Limit	100
Graphene	0.2	< Detection Limit	100
Sawdust	0.2	< Detection Limit	100
Banana Peel Powder	0.2	< Detection Limit	100
Orange Peel Powder	0.2	< Detection Limit	100

Activated carbon has a greater capacity for adsorption and a wide surface area. In order to attain 100% displacement efficiency, a larger initial concentration was used while utilizing the other materials because of their lesser effectiveness in comparison to activated carbon. When 0.03 g of activated carbon was combined with 0.005 g of Fe3O4 nanoparticles, the removal efficiency was greater than when 0.03 g of activated carbon was used alone. The synergistic impact between the huge surface area of activated carbon and the nanoparticle Fe3O4 is responsible for this increase. Furthermore, Improved pollutant removal resulted from an increase in the total surface area accessible for adsorption to about 0.035 g. The overall adsorption performance is improved by the nanoparticles' tiny particle size (around 25 nanometers).

Step Two: BB Field Water

Oil content before and after filtration (BB Field)

- Before filtration: 25 mg/L
- After filtration: 1.1 mg/L
- Filtration removal efficiency: 95.6%

Table(3) the Oil concentration (mg/L)before and after filtration

sample	Oil content percentage		
	Before filtration process mg/l	After filtration process mg/l	Removal efficiency%
Produced water	25	1.1	95.6

Before filtration, the oil concentration in the AA field sample was 306 mg/L, while the BB field sample had a significantly lower concentration of 25 mg/L. After filtration, the remaining concentrations were 30.7 mg/L and 1.1 mg/L, respectively. Despite using the same filtration setup, the AA sample showed a higher residual oil content due to the much higher initial concentration.

Table 4: Oil content concentration for produced water after treatment with different materials calculated relative to post-filtration concentration of 1.1 mg/L

Materials used	Concentrations	Oil content percentage	Removal efficiency%
Activated Carbon	0.02	0.5	54.5
Nano Particles Fe_3O_4 0.005+Activated Carbon	0.02	< Detection Limit	100

Despite employing the same procedure and adsorbent dosage (0.02 g), the removal efficiency of activated carbon alone varied between AA (79.4%) and BB (54.5%) fields. This variation is primarily attributed to the difference in initial post-filtration oil concentration (30.7 mg/L in AA vs. 1.1 mg/L in BB), as lower solute concentrations provide a smaller mass-transfer driving force between the aqueous phase and the adsorbent surface, in addition to inherent variations in formation water matrix.

Iron concentration before and after addition of activated carbon (Measured by AAS, contact time: 150 min)

- Before treatment: 720 mg/L
- After treatment (1g Activated Carbon): < Detection Limit < 0.05 mg/L
- Removal efficiency: approx. 100%

Table(5) the concentration iron before and after addition activated carbon

sample	Heavy metals (Iron)		
	Before filtration process mg/l	After filtration process mg/l	Removal efficiency%
Produced water	720	< 0.05	100

The iron removal experiments were conducted at the natural pH of the produced water (measured at pH 7.4 ± 0.2) and a contact time of 150 min at room temperature (25 ± 2 °C). The high apparent removal efficiency (from 720 mg/L to < 0.05 mg/L) is attributed to a dual mechanism: physical adsorption onto the high surface area of activated carbon (>1000 m^2/g) combined with micro-precipitation of iron hydroxides at near-neutral pH conditions.

Conclusions

The results of this study unequivocally show that generated water from oil fields contains high concentrations of oil and other impurities that need to be cleaned before being disposed of or used again. Oil concentration was significantly reduced through physical treatment utilizing the adsorption approach, particularly when activated carbon and nanomaterials were used. According to the experimental findings, raising the activated carbon concentration enhanced oil removal effectiveness, sometimes reaching 100%. However, it was discovered that the combination of activated carbon and Fe3O4 nanoparticles was the most effective adsorbent, especially at a concentration of 0.005 g of Fe3O4, which achieved 100% oil removal in both AA and BB fields of oil. This combination showed great efficacy even at low concentrations, demonstrating its potential as an economical and sustainable method of treating generated water. The employment of eco-friendly substitutes is further supported by the exceptional removal efficiencies of natural materials including graphene, sawdust, banana peels, and orange peels. Overall, the study shows that the combination of Fe3O4 nanoparticles and activated carbon performs the best of all the materials studied, making it a viable choice for use in the treatment of wastewater from oil fields.

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