e-palli

JOURNAL OF INNOVATIVE RESEARCH (JIR)

ISSN: 2837-6706 (ONLINE)

VOLUME 1 ISSUE 2 (2023)

PUBLISHED BY

E-PALLI PUBLISHERS, DELAWARE, USA

Journal of Innovative Research (JIR)
Volume 1 Issue 2, Year 2023
ISSN: 2837-6706 (Online)
DOI: https://doi.org/10.54536/jir.v1i2.1567
https://journals.e-palli.com/home/index.php/jir

Some Current Technologies of Produced Water Treatment: An Overview

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Article Information

Received: April 08, 2023

Accepted: May 04, 2023

Published: July 28, 2023

Keywords

Produced Water, Oilfield, Adsorption, Chemical Precipitation, Activated Sludge

ABSTRACT

Produced water is considered the largest waste stream generated in the oil and gas industries, which has a high concentration of hydrocarbons, heavy metals, and other pollutants. As the activity in the industries increases, the generated produced water has also increased worldwide. Therefore, treating it for reusing becomes very important from an environmental point of view. This paper aims to examine the importance of produced water treatment, the capacity of produced water as well as management, the reuse of oilfield-produced water, and some of the current methods available for produced water treatment. Production water treatment could be achieved with different processes or methods including physical, chemical, and biological approaches. The physical method usually involves filtration systems that uses screens, sand, etc to eliminate large suspended materials. The chemical method is a process of decreasing the harmful nature of an effluent by using some particular chemical. It also helps to recover appreciated by-products from harmful wastes, which reduces the general cost of waste disposal. While the biological method is to degrade organic compounds that are existing in the waste by microorganisms (aerobic and/or anaerobic). Raw-produced water is toxic, by using suitable technology, it can be treated for different reuse even as drinking water, especially for countries that suffer from water scarcity.

INTRODUCTION

Water is a fundamental necessity of all organisms, which makes it crucial for life. The fast-growing economic and industrial rates have led to a rapid increase in population and development (Chen, 2018). The world is witnessing development and advancement in the industry because several industrial methods are being applied (Zhang *et al.*, 2015). The industrialization has produced substantial amounts of wastewater at high rates, most of the time disposed of with no proper management and treatment (Varjani *et al.*, 2019; Jafarinejad & Jiang, 2019). A classic oil reservoir generally comprises natural gas, oil, and water. This water from the reservoir is known for producing water. Produced water is a unique distinct record significant waste streams in the gas and oil industry (Sirivedhin & Dallbauman, 2004). Since Edwin Drake drilled the first oil well in the late 1850s, the demand for petroleum has continued to increase (Ebenezer & George, 2014). The world's daily petroleum consumption is projected to increase from 85 million barrels in 2006 to 106.6 million barrels by 2030 (Energy Information Administration, 2009). Despite its implication, petroleum is produced with enormous volumes of waste, with wastewater accounting for more than 80% of liquid waste (Azetsu-Scott *et al.*, 2007), and as high as 95% in aging oilfields (Kaur *et al.*, 2009). The ratio of oil and produced water is generally 1:3 for most of the oil well (Munirasu *et al.*, 2016). The chemical composition of produced water is complex. It comprises a combination of several components such as phenols, organic acids, dispersed oil, dissolved hydrocarbons, metals, and deposits of chemical compounds added to the production line or separation (Simões *et al.*, 2020). There is a difference in the water composition level because of geological formation, the lifespan of the reservoir, and the type of hydrocarbon produced (Igunnu & Chen, 2012). The final disposition can pollute the surface water, groundwater, and soil if the produced water is not appropriately treated. Therefore, the concentrations of these components in produced water need to be reduced or completely removed before disposing it into the environment, reuse for irrigation, or reinjected into reservoirs (Ahmadun *et al.*, 2009; Weschenfelder *et al.*, 2016; Meneses *et al.*, 2017; Al-Ghouti *et al.*, 2019).

What is Produced Water

Produced water is water that is returned to the surface through an oil or gas well. It comprises natural formation water and water injected into the formation as part of a fracture stimulation process or an enhanced recovery operation. Produced water is typically generated for the lifespan of a well (Figure 1). Concerning formations of the subsurface, rocks are infiltrated with a mixture of water, oil, and gas. It's assumed that rocks are totally soaked with water in most oil-bearing foundations because of attack and trapping of oil. This water can flow from below, above, or inside the hydrocarbon zone or can move because of condiments that were added for

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the period of production and extraction. The outcome of any water contained by the hydrocarbon region that being produced with natural gas or crude oil, and transported up by good pumps is named the produced water (Igunnu & Chen, 2014). Figure 2 shows a typical oil field production. Produced water is characterized by a high salt and oil content requiring a specific means of treatment to decontaminate them. Normally, produced water comprises some high concentrations of aromatic hydrocarbons e.g PAH (polycyclic aromatic compounds), NPD (naphthalene, phenanthrene dibenzothiophene), BTEX (benzene, toluene, ethylbenzene, xylene), radioactive substances, minerals, waxes, dissolved gases, scale products, dissolved oxygen, and microorganisms (Igunnu & Chen, 2012). Those organic compounds harm human wellbeing and the environment, such as high mutagenic and carcinogenic risks, high resistance to biodegradation, tumor, and cancer, and high toxicity to marine living things (Jing *et al.*, 2014). Other biological impacts due to the presence of produced water include high risk in the endocrine, non-endocrine, and reproductive systems (Silva *et al.*, 2019).

Figure 1: Sketch of a Typical Reservoir (Ebenezer & George, 2014)

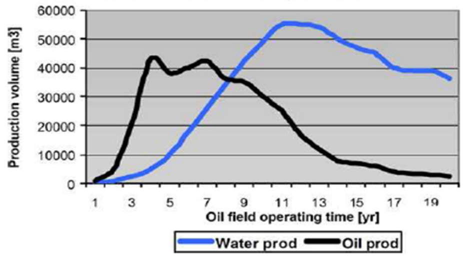

Figure 2: Oilfield Production Profile Produced Water (Igunnu & Chen, 2014)

Table 1: Oilfield Produced Water Composition (Fakhru'l-Razi *et al.*, 2009)

Parameter	Minimum value	Maximum value	Heavy metal	The minimum value (mg/l)	The maximum value (mg/l)
Density (kg/m^3)	1014	1140	Calcium	13	25 800
Conductivity (mS/cm)	4200	58 600	Sodium	132	97 000
Surface tension (dyn/cm)	43	78	Potassium	24	4300
pH	4.3	10	Magnesium	8	6000
TOC (mg/l)	0	1500	Iron	<0.1	100
TSS (mg/l)	1.2	1000	Aluminium	310	410
Total oil (IR; mg/l)	2	565	Boron	1.3	95
Volatile (BTX; mg/l)	0.39	35	Barium	1.3	650
Base/neutrals (mg/l)	-	<140	Cadmium	<0.005	0.2
Chloride (mg/l)	80	200 000	Copper	<0.02	1.5
Bicarbonate (mg/l)	77	3990	Chromium	0.02	1.1
Sulphate (mg/l)	<2	1650	Lithium	3	50
Ammoniacal nitrogen (mg/l)	10	300	Manganese	<0.004	175
Sulphite (mg/l)	-	10	Lead	0.002	8.8
Total polar (mg/L)	9.7	600	Strontium	0.02	1000
Higher acids (mg/l)	<1	63	Titanium	<0.01	0.7
Phenol (mg/l)	0.009	23	Zinc	0.01	35
Volatile fatty acids (mg/l)	2	4900	Arsenic	<0.005	0.3
			Mercury	<0.005	0.3
			Silver	<0.001	0.15
			Beryllium	<0.001	0.004

Importance of Treatment for Produced Water

It is significant to treat the wastewater associated with crude oil operations, because the untreated water may affect the quality of the oil, its price, and its properties (Abdulaziz *et al.*, 2021). Also, it affects the environment, human health, groundwater, and soil, therefore there is a need to deal with it for free crude oil, water, suspended solids, and other materials (Mohammed & Jasim, 2019). Many studies showed that oil-field-produced wastewater can cause harms in the surroundings in numerous means (Al-Haleem *et al.*, 2010):

- Plants will be harmed by dehydration and die because of the rise of soluble salts.

• Clay deflection caused by over-sodality.

• Aquatic environment will be damaged because of the reduction of oxygen levels.

• The influence of chemical additives such as corrosion inhibitors and H_2S scavengers.

• Deep establishment plugging by suspended solids that leads to rise in injection pressure and a decrease in the flow rate of injected produce water.

Produced Water Volume and Management

There is no fixed volume for the produced water, it depends on the reservoir location and the extraction technology that was activated (Veil, 2015). Produced water volume in a certain reservoir differs from time to time. At the commencement of the extraction process, the produced water amount is actual small, but as the production is aging, the produced water in the reservoir increases (Nasiri & Jafari, 2017). The management of wastewater in oil fields has a great motivation to people, because they are interested in the aquatic environment being safe for all human beings, and this has motivated many institutes to develop novel strategies for the treating of effluents and reusing the water (Bastos *et al*., 2020). The purpose of management of produced water treatment is costly but should be considered in any production plan which has an effective role in making the economic recovery willpower of the reservoir that may lead to having a substantial number of recoverable hydrocarbons in the reservoir. There are alternative ways to manage produced water (Nasiri & Jafari, 2017):

• The produced water could be used for commercial purposes after proceeding with a significant treatment to meet the minimum limits for reuse in irrigation, rangeland restoration, and live organism consumption.

• The discharging of produced water to the aquatic environment after a specific treatment to meet the required discharge regulations of the environment.

• It can be injected again into the same formation of a reservoir or a different appropriate formation to reduce cost and compensate for reservoir pressure.

• The discharging of produced water to the aquatic environment after a specific treatment to meet the required discharge regulations of the environment.

• Reusing the produced water in the drilling and maintenance operations of the well sites following treating it to meet the desired quality.

Environmental Impacts of Produced Water

From the mid-1800s, when the first oil and gas wells were drilled and operated, the environmental impacts caused by the disposal of produced water have been reported (Katie *et al*., 2011). The most commonly reported environmental concerns are; surface water, groundwater, degradation of soils, and ecosystems (Otton, 2006). Because most produced water contains high levels of dissolved ions (salts), hydrocarbons, and trace elements. Therefore, discharging untreated produced water may be harmful to the surrounding environment.

Human Health Impact of Produced Water

In most developing countries like Nigeria, majority of the people lack access to safe and potable water, especially people from oil-producing communities. These people's major drinking water sources are from the rivers, streams, leaks, and groundwater. Wastewater from oil production operations is discharged into the environment, either on land or water bodies, which have not been properly treated. This increases the risk to human health because of more contamination of drinking water by petroleum. These effluents are known to have some contain heavy metals in concentrations beyond acceptable limits, which cause metabolic failures in humans (Ambrose, 2020). Most chemicals from crude oil, like benzene, toluene, ethylbenzene, xylenes, and others are proven carcinogenic, teratogenic, and mutagenic. The high occurrence of respiratory illnesses, asthma, cancer, and birth deformity in most of oil producing communities in Nigeria has been ascribed to oil contamination (Ambrose, 2020).

Treatment Methods

Different types of treatment can be employed to treat wastewater produced by the petroleum industry, such as; physical, chemical, and biological methods.

Physical Treatment Methods

Different physical methods are widely used for wastewater treatment, especially the produced water, such as.

Adsorption

This is the best favorable treatment techniques for reaching the best water quality because it can minimize the contaminant concentration to the least levels. Its effectively used to eliminate heavy metals, organic and inorganic compounds, manganese, iron, TOC, COD, Oil, BTEX compounds, and synthetic organic chemicals. On the other hand, the waste disposal requirement for the produced waste and employing a media to the regeneration process of media besides the necessity to regenerate the absorbent material frequently gives an elevated cost for system installation or maintenance (Alslaibi *et al*., 2013). Activated carbon is one of the best adsorbents that are favorable for water treatment over other processes due to its simplicity, economy, and efficiency. Cheap and good adsorbent-like activated carbon is conducted through a system transformation that is developed to achieve more pores by increasing the surface area (Bhatnagar *et al*., 2013).

Filtration

The filtration process is effective for removing Oil and grease, COD and Nitrogen, Ammonia, Chloride, Phosphorus, TOC, TSS, Sulphate, TDS, salts, and Turbidity. Alzahrani *et al*., (2013), examined two methods of the microfiltration process, the first one is the dead end and the second is the crossflow. These methods were applied to oil emulsion which was prepared from motor oil (classic oil 20W-50) and vegetable oil. In the dead-ends method, the rejection percentage reached 97.8 %, while in crossflow it reached 98% with a recovery ratio of 44.8%. The nanoporous hydrophobic resonating fibers membranes can expel almost all the TDS pollutants from the wastewater, but after 100 hr of continuous operation, the effluent was suitable for industrial reuse (Kusworo *et al.*, 2018). Abdulraheem *et al.*, (2020), also use natural filtration by utilizing agricultural wastes (1:1 ratio of Reed and Straw) to remove iron from synthetic wastewater, and the result was about 33% of iron was removed by the natural wastes. Membrane bioreactors (MBRs) in pretreatment help to decrease about 85% of COD concentration.

Flotation

This depends on the gas bubble generation, which can separate the suspended particles that cannot be extracted through sedimentation. This can be attained by injecting gas bubbles into the influent wastewater, then the suspended pollutant particulates and oil droplets will be attached to bubbles and will rise, then the skimming process can remove the produced formation. Two different gas flotation technologies differ in the means of producing fine bubbles and controlling the bubble size these techniques are induced gas flotation (IGF) and dissolved gas flotation (DGF) (Fakhru'l-Razi *et al.*, 2009; Abdulaziz *et al.*, 2021).

Chemical Treatment Methods

Chemical Precipitation

Coagulation and flocculation can be used to eliminate suspended and colloidal particles, but are not effective for removing dissolved constituents. Lime softening is the usual process for water softening. In the modified hot lime process, produced water having 500 ppm sulfides, and 200 ppm, 2000 ppm hardness, and 10,000 ppm TDS, oil could be successfully converted to steam generator quality feed-water. In this process, alkali consumption and sludge production could be reduced by 50% in comparison with conventional hot lime (Fakhru'l-Razi *et al.*, 2009).

Chemical Oxidation

Chemical oxidation is a common technique for disintegrating stubborn chemicals in wastewater in which a catalyst, tough oxidant, and irradiation are used, except ozone treatment (Renou *et al.*, 2008).

Electrochemical Process

In a laboratory pilot-scale plant that included double anodes with the 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. These processes produced Mn2+ ions oxidized and coagulated organic pollutants including bacteria (Ma & Wang, 2006).

Photocatalytic Treatment

Fujishima & Honda, (1972), reported the photocatalytic deterioration of water on TiO_2 electrodes. This method can be employed for a variety of pollution remediation. The general process for organic pollutant treatment by the photocatalytic process is as follows;

$$\text{Organic pollutant} + O_2 \xrightarrow{\text{semiconductor.hv}} CO_2 + H_2O + \text{mineral acids}$$

In a proposed process for oilfield-produced water treatment before photocatalytic reaction, wastewater pH was increased to 11 by soda addition. After flocculation and settling, the supernatant was filtered. The photocatalytic reaction was carried out in an open reactor with 60 mL of previously clarified produced water and an adequate amount of photocatalyst-TiO_2. A high-pressure 250 W mercury lamp illuminated the suspension at 298 K. This method could reduce the toxicity of produced water (Bessa *et al.*, 2001).

Biological Treatment Methods

In the biological treatment method, there are two microorganisms; aerobic and anaerobic microorganisms were used in the treatment of produced water. In aerobic treatment, researchers used activated sludge, trickling filters, sequencing batch reactors (SBRs), chemostat reactors, biological aerated filters (BAF), and lagoons. Four sources of microorganisms were studied in biological treatment; naturally occurring microorganisms, commercial microorganisms, specific groups of microorganisms, and acclimated sewage sludge.

Activated Sludge

This is a common method used in aerobic wastewater treatment processes by adsorbing and occluding soluble and insoluble materials. The total petroleum hydrocarbon removal efficiency that can be conducted through the activated sludge is 98.5% (Tellez *et al.*, 2005), and 40% COD concentration removal. It is cheap and clean technology, but its disadvantage is that it needs a large amount of oxygen and big dimensions filter. It required further treatment for separating precipitated solids, biomass, and dissolved gases (Freire *et al.*, 2001). This type of treatment is effective in removing COD, total petroleum hydrocarbons, suspended solids, and heavy metals.

Microalgae-Based Process

This can be employed as an alternate source of energy and power generation, its remediation of contaminated effluents can be achieved through utilizing microalgae according to the ability through getting a benefit of some pollutants as a feed such as Water-soluble fraction (WSF) gasoline, BTEX, Nitrogen and Phosphorus. Parachlorella Kessler which is a specific microalgal species can utilize BTEX as a sole source of carbon also BTEX can affect the growth of microalgae. But, sometimes pollutants concentration increases with time if the microalgae cultures are inhibited (Johnson *et al.*, 2016; Takáčová *et al.*, 2015).

Biological Aerated Filters (BAF)

This process does not require post-treatment or use of any chemicals and can apply to a large quantity of water to reduce the concentrations of COD, BOD, SS, nitrogen, oil, and ammonium, and quality with expected a long-life cycle with little maintenance. This process was declared to remove efficiently different pollutants such as COD, BOD, nitrogen, oil, and SS with excellent removal percentage (Delin *et al.*, 2007). But major drawbacks are the need to be free of sludge and solids that generated and created sediments in the basins where the removal costs nearly half of the entire process cost (Abdulaziz *et al.*, 2021).

Eman *et al.*, (2022), studied the removal of organic pollutants from produced water by batch adsorption treatment on chemical oxygen demand (COD), oil, and turbidity of the produced water, which go with the production and exploration of oil, subsequently treating utilized powdered activated carbon (PAC), synthetic zeolite type X (XSZ), and clinoptilolite natural zeolite (CNZ). The effects of adsorbent dosage, time, pH, oil concentration, and temperature were studied to find the best operating conditions. At a PAC adsorbent dose of 0.25 g/100 mL, maximum oil removal efficiencies (99.57, 95.87, and 99.84%). Moreover, when zeolite X was used at a concentration of 0.25 g/100 mL, the highest turbidity removal efficiency (99.97%) was achieved.

Udeagbara *et al.*, (2021), studied on the Niger Delta oil fields produced water treatment, using a sequential mixture of bio-adsorbents. Four local materials, banana peels (I), orange peels (II), sponge gourd (*Luffa cylindrica*) (III), and palm kernel fibers (IV) were combined to treat the Niger Delta oil fields produced water. The adsorbents were ground into powder, and sieved (150 µm sieve size, Group A) and (300 µm sieve size, Group B). The produced water was treated with the bio-adsorbents consecutively in the adsorption column for over 7 hr. The result shows that the 150 µm sieve size of sample R, lead (Pb), cadmium (Cd), copper (Cu), and chromium (Cr) were completely (100%) adsorbed from the produced water after 8 hours of treatment while other metals (Ni, Fe, Mg, Zn, Mn, Ca, Ar, B, Sn, Ba) were found to be 86.11%, 90.76%, 39.25%, 94.40%, 43.55%, 99.26%, 54.62%, 44.53%, 84.52%, and 47.37%, respectively. while the reduction in 300 µm sieve size was 23.48% for Pb, 80.20% for Ni, 71.42% for Cd, and 19.73% for Cu. 43.65% for Fe, 34.79% for Mg, 12.67% for Cr, and 88.8%.

Omer *et al.*, (2020), studied the effect of process parameters on the photocatalytic degradation of phenol in oilfield-produced wastewater using ZnO/Fe_2O_3 nanocomposites. After solar radiation of 180 min, the highest phenol degradation of 92.7% was achieved using the ZnO/Fe_2O_3 photocatalyst, with calcination temperature at 400 °C. The study confirmed that phenol degradation was noticeably controlled by some parameters e.g calcination temperature of the ZnO/Fe_2O_3 nanocomposite, catalyst loading, initial phenol concentration, and pH of the wastewater resulting in the highest phenol degradation using the ZnO/Fe_2O_3 nanocomposite calcined at 400 °C, initial phenol concentration of 0.5 mg/L, catalyst loading of 3 mg/L and pH of 3.

The Reuse of Oilfield-Produced Water

The freshwater shortage is increasing over time, because of the growth of population and cost of living. Therefore, the reusing of produced water is a major focus of attention if appropriate treatment is applied. The attention to demand, recycling, and reusing of water could meet the needs of the communities, but meeting the standards for drinking water is a major concern. Therefore, produced water treatment needs more than one stage. There are alternative uses of produced water like irrigation, livestock watering, firefighting, and many industrial purposes. According to the produced water criteria, the treatment stage that is desired depends on the implementation, and where it will be utilized. For instance, the least treatment efficiency is needed in oil and gas industries while a high treatment efficiency is needed for drinking water. Ultimately, the cost is the most important parameter for the treatment and the reuse (Bagheri *et al.*, 2018).

CONCLUSION

The shortage of freshwater resources and environmental problems caused by oilfields and other industries have drawn attention to the treatment of produced water. This review article examined the importance of produced water treatment, the capacity of produced water and management, the reuse of oilfield-produced water, and some of the current methods available for the treatment of produced water. In produced water treatment, only one technology cannot meet appropriate effluent characteristics, therefore, two or more treatment techniques can be used in a series of operations. The choice of the best technology is based on produced water chemistry, cost-effectiveness, space availability, reuse and discharge plans, durable operation, and by-products. To reduce the environmental hazards of industries and to meet the water demands, it is necessary to enhance the produced water treatment to eliminate the environmental impacts of the industry. Raw-produced water is toxic, by using suitable technology it can be treated for different reuse even as drinking water, especially for countries that suffer from water scarcity.

REFERENCES

Abdulaziz, J. A., Hatem, A. G., and Mahdi, N. R. (2021). Oilfield-produced water characteristics and treatment technologies: a mini-review. *IOP Conf. Series: Materials Science and Engineering 1058*, 012063. https://doi.org/10.1088/1757-899X/1058/1/012063.

Abdulraheem, F. S., Al-Khafaji, Z. S., Hashim, K. S., Muradov, M., Kot, P., and Shubbar, A. A (2020). A natural filtration unit for removal of heavy metals from *water IOP Conf. Ser. Mater. Sci. Eng. 888*.

Ahmadun, F. R., Pendashteh, A., Abdullah, L.C., Biak,

D. R. A., Madaeni, S. S., and Abidin, Z. Z. (2009). Review of technologies for oil and gas-produced water treatment. *Journal of Hazardous Materials, 170*(2-3), 530-551.

Al-Ghouti, M. A., Al-Kaabi, M. A., Ashfaq, M. Y., Da´na, D. A. (2019). Produced water characteristics, treatment, and reuse: A review. *Journal of Water Process Engineering, 28*, 222-239.

Al-Haleem, A. A, Abdulah, H. H, and Saeed, E. A. J. (2010). Components and Treatments of Oilfield Produced Water. *Al-Khawarizmi Eng. J. 6,* 24–30.

Alslaibi, T. M., Abustan, I., Ahmad, M. A., and Abu, F. A. (2013). Comparison of agricultural by-products activated carbon production methods using surface area response Activation processes. *Caspian J. Appl. Sci. Res, 2* 18-27

Alzahrani, S., Mohammad, A. W., Abdullah, P., and Jaafar, O. (2013). Potential tertiary treatment of produced water using highly hydrophilic nanofiltration and reverse osmosis membranes. *J. Environ. Chem. Eng. 1*, 1341–9.

Ambrose, O. E. (2020). Environmental Impact of Oil on Water: A Comparative Overview of the Law and Policy in the United States and Nigeria. *Denver Journal of International Law & Policy, 24*(1).

Azetsu-Scott, K., Yeats, P., and Wohlgeschaffen, G. (2007). Precipitation of heavy metals in produced water: influence on contaminant transport and toxicity. *Mar Environ Res. 63*, 146–67.

Bagheri, M., Roshandel, R., and Shayegan, J. (2018). Optimal selection of an integrated produced Bastos P. D. A., Santos M. A., Carvalho P. J., and Crespo J. G (2020). Reverse osmosis performance on stripped phenolic sour water treatment – A study on the effect of oil and grease and osmotic pressure *J. Environ. Manage.* 261.

Bessa, E., Sant'Anna, G. L., Dezotti, M. (2001). Photocatalytic/H2O2 treatment of oil field produced waters. *Appl. Catal. B, 29*, 125–134.

Bhatnagar, A., Hogland, W., Marques, M., and Sillanpää, M. (2013). An overview of the modification methods of activated carbon for its water treatment applications. *Chem. Eng. J., 219,* 499–511.

Chen, Y. C, (2018). Evaluating greenhouse gas emissions and energy recovery from municipal and industrial solid waste using waste-to-energy technology. *J. Clean. Prod., 192*, 262–269.

Delin, S. U., Jianlong, W., Kaiwen, L., and Ding, Z. H. O. U. (2007). Kinetic performance of oil- the field produced water treatment by biological aerated filter .*Chinese J. Chem. Eng., 15,* 591–4.

Ebenezer, T. I. and George, Z. C. (2014). Produced water treatment technologies. *International Journal of Low-Carbon Technologies. 9*, 157–177.

Eman, H. K., Thamer, J. M., Nourollah, M., Ali, D. S., Tatjána, J., and Thamer, A. A. (2022). Removal of organic pollutants from produced water by batch adsorption treatment. *Clean Technologies and Environmental Policy, 24*, 713–720. https://doi.org/10.1007/s10098-021-02159-z.

Energy Information Administration (2009). International energy outlook. US Department of Energy, DOE/EIA-0484(2009). www.eia.doe.gov/oiaf/ieo/index.html.

Fakhru'l-Razi, A., Alireza, P., Luqman, C. A., Dayang, R. A. B., Sayed, S. M., and Zurina, Z. A. (2009). Review of technologies for oil and gas-produced water treatment. *Journal of Hazardous Materials, 170.* 530–551.

Freire, D. D. C., Cammarota, M. C., and Sant'Anna, G. L. (2001). Biological treatment of oil field wastewater in a sequencing batch reactor. *Environ. Technol. 22,* 1125–35.

Fujishima, A., and Honda, K. (1972). Electrochemical photolysis of water at a semiconductor. *Nature, 238*, 37–38.

Igunnu, E. T. and Chen, G. Z, (2014). Produced water treatment technologies. *Int. J. Low-Carbon Tech.* 1-21.

Igunnu, E. T. and Chen, G. Z, (2012). Produced water treatment technologies. *International Journal of Low-Carbon Technologies,* 9, 157-177.

Jafarinejad, S., Jiang, S. C. (2019). Current technologies and future directions for treating petroleum refineries and petrochemical plants (PRPP) wastewaters. *J. Environ. Chem. Eng., 7*, 103326.

Jing, L., Chen, B., Zhang, B., Zheng, J., and Liu, B. (2014). Naphthalene degradation in seawater by UV irradiation: The effects of fluence rate, salinity, temperature, and initial concentration. *Mar. Pollut. Bull. 81*, 149–156.

Johnson, R. J., Jurawan, I., Frenzel, M., and Price, A. C. (2016). The identification and mechanism of a Scenedesmus spp. causing bio-fouling of an oil field-produced water treatment plant. *Int. Biodeterior. Biodegrad. 108,* 207–13.

Katie, G., Katharine, D., and Steve, D. (2011). Oil and Gas Produced Water Management and Beneficial Use in the Western United States. Science and Technology Program Report No. 157.

Kaur, G., Mandal, A. K., and Nihlani, M. C. (2009). Control of sulfidogenic bacteria in produced water from the Kathloni oilfield in northeast. *India. Int Biodeterior Biodegrad, 63,* 151–5.

Kusworo, T. D., Aryanti, N. Q., and Utomo, D. P. (2018). Oilfield produced water treatment to clean water using integrated activated carbon-bentonite adsorbent and double stages membrane process. *Chem. Eng. J., 347* 462–71.

Ma, H. and Wang, B. (2006). Electrochemical pilot-scale plant for oil field produced wastewater by M/C/Fe electrodes for injection. *J. Hazard. Mater. B, 132*, 237–243.

Meneses, A. C., Weber, O. B., Crisóstomo, L. A., and Andrade, D. J. (2017). Biological soil attributes in oilseed crops irrigated with oilfield produced water in the semi-arid region. *Revista Ciência Agronômica, 48*(2), 231-241.

Mohammed, T. J. and Jasim, J. M. (2019). Treatment of Wastewater Associated with Crude Oil in Reservoirs. *J. Pet. Res. Stud. JPRS, 6*, 64–85.

Munirasu, S., Mohammad, A. H., and Banat, F. (2016). Use of membrane technology for oil field and refinery produced water treatment – A review. *Process Safety and Environmental Protection, 100,* 183-20.

Nasiri, M. and Jafari, I. (2017). Produced water from oil-gas plants: A short review on challenges and opportunities Period. Polytech. *Chem. Eng., 61,* 73–81.

Omer, A. H., Abdurahman, H. N., Rushdi, B., and Bamidele, V. A. (2020). Effect of Process Parameters on the Photocatalytic Degradation of Phenol in Oilfield Produced Wastewater using ZnO/Fe2O3 Nanocomposites. *Bulletin of Chemical Reaction Engineering & Catalysis, 15*(1), 128-136.

Otton, J. K. (2006). Environmental Aspects of Produced-water Salt Releases in Onshore and Coastal Petroleum-producing Areas of the Conterminous U.S. A Bibliography. U.S. Geological Survey. U.S. Department of the Interior. Reston, Virginia. Open-File Report 2006-1154.

Renou, S. J., Givaudan, G., Poulain, S., Dirassouyan, F., and Moulin, P. (2008). Landfill leachate treatment: review and opportunity. *J. Hazard. Mater., 150*, 468–493.

Silva, L. S., Silva, D. P., and Ruzene, D. S. (2020). Produced Water: An overview of treatment technologies. *International Journal for Innovation Education and Research, 8*(04). www.ijier.net.

Silva, P. C., Ferraz, N. P., Perpetuo, E. A., Asencios, Y. J. O. (2019). Oil-produced water treatment using advanced oxidative processes: Heterogeneous-photocatalysis and photo-Fenton. *J. Sediment. Environ. 4,* 99–107.

Simões, A. J. A., Macêdo-Junior, R. O., Santos, B. L. P., Sirivedhin, T., and Dallbauman, L. (2004). An organic matrix in produced water from the Osage-Skiatook Petroleum Environmental Research site, Osage County, Oklahoma. *Chemosphere, 57*(6), 463-469.

Takáčová, A., Smolinská, M., Semerád, M., and Matúš, P. (2015). Degradation of btex by microalgae Parachlorella kessleri. *Pet. Coal 57*, 101–7.

Tellez, G. T., Nirmalakhandan, N., and Gardea-Torresdey, J. L. (2005). Kinetic evaluation of a field scale activated sludge system for removing petroleum hydrocarbons from oilfield-produced water. *Environ. Prog., 24*, 96–104.

Udeagbara, S. G., Isehunwa, S. O., Okereke, N. U., Oguamah, I. U., Kerunwa, A., and Nwanwe, O. (2021). Treatment of produced water from Niger Delta oil fields using sequential mixture of bio-adsorbents, *Cogent Engineering, 8*(1), 1939927, https://doi.org/

Varjani, S., Kumar, G., and Rene, E. R. (2019). Developments in biochar application for pesticide remediation: Current knowledge and future research directions. *J. Environ. Manag., 232*, 505–513.

Veil, J. (2015). US Produced Water Volumes and Management Practices in 2012 report prepared for the Groundwater Protection Council. water treatment system in the upstream of oil industry. *Process Saf. Environ. Prot., 117,* 67–81.

Weschenfelder, S. E., Fonseca, M. J. C., Borges, C. P., and Campos, J. C. (2016). Application of ceramic membranes for water management in offshore oil production platforms: Process design and economics. *Separation and Purification Technology, 171*, 214-220.

Zhang, X., He, W., Ren, L., Stager, J., Evans, P. J., and Logan, B. E. (2015). COD removal characteristics in air-cathode microbial fuel cells. *Bioresour. Technol. 176*, 23–31.