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Original Article

Life Cycle Assessment (LCA) of the Wastewater in a Crude Oil Desalination Plant in Southwest Iran using Simapro9 Software

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Abstract

Background & Aims: wastewater from upstream oil industries, including crude oil desalination plants, is an important environmental and health challenge. The present research has been carried out to assess the life cycle (LCA) of the wastewater from the desalination process in a crude oil desalination plant in the southwest of Iran in 2023.
Materials and Methods: This descriptive-applied study investigated the LCA of the crude oil desalination process using Simapro9 software and the amount of wastewater flow in the process based on the ILCD 2011 Midpoint V1.03 method and its effects. Quantitative and qualitative parameters of wastewater, petroleum compounds (ASTM D 3921-96), heavy metals (Atomic Absorption- EM900), polycyclic aromatic hydrocarbons PAHs (ISO 17993GC/MS), and other polluting factors related to desalination wastewater were analyzed. The boundaries of the system were determined, and the production of one barrel of crude oil was considered a functional unit.
Results: The results showed that the values of total suspended solids (1654 mg/L), total dissolved solids (121650 mg/L), total sulfur (0.78%), chemical oxygen demand (752 mg/L), and Oil and Grease (63 mg/L) in the wastewater sample significantly exceeded the EPA wastewater treatment standards. The average amounts of magnesium, iron, nickel, and vanadium were estimated at 2.73, 2.52, 1.63, and 1.14 mg/L, respectively, and the total of PAHs was 47.41 mg/L. The results of the LCA showed that the effects of soil acidification at 22%, global warming at 20%, the effect of toxicity on humans and the environment at 17%, solid particles at 15%, and carcinogenicity and eutrophication at 9% were the most important environmental effects resulting from the desalination process of crude oil.
Conclusion: The results of this research showed the side effects of the desalination process in the production of salty petroleum wastewater. Therefore, the implementation of environmental management programs for the optimal treatment of wastewater and its reuse is an effective solution to reduce its effects.

Keywords: Crude oil desalination, ILCD 2011, Life cycle assessment, Simapro9, Petroleum wastewater

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1. Introduction

A significant portion of the environmental pollution in today's world stems from the extraction, processing, and consumption of petroleum products [1, 2]. One of the major environmental challenges in the oil industry is the extraction of saline-oily water along with crude oil [3]. These wastewaters pose a considerable threat to the surrounding environment owing to their specific qualitative (very large volume) and quantitative characteristics (high soluble salts, petroleum substances, volatile and non-volatile organic compounds, and other hazardous pollutants for the environment) [4].

According to statistical reports from the Oil and Gas Producers Organization, energy and water consumption during crude oil production and processing was estimated to exceed 3.99×10^7 m^3/day in 2020, which is equivalent to 16% of the total freshwater consumption globally. This consumption level is projected to double by 2035 based on the anticipated increase in oil demand. The required water for such production varies between 0.47 to 7.2 liters per barrel of oil. Between 80% and 90% of the water used in the process is discharged as wastewater [5]. Therefore, there is a significant connection between oil production and pollution in the environment and surface waters, in addition to their ecological effects [6].

The wastewater from oil desalination plants consists of a mixture of oil, gas, and water (usually saline), which are separated into three phases (oil, water, and gas) during processing [7]. The produced wastewater from the processing of sour and saline crude oil contains about 80-95% free water, while the remainder is in the form of emulsion particles of saline water in crude oil [8]. The volume of extracted saline water tends to increase over time, exceeding even 50 m^3/hour [9]. This wastewater contains a wide range of pollutants, including highly soluble salts (50 to 20,000 ppm), Oil and Grease, volatile and non-volatile

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organic compounds, aromatic and aliphatic compounds, heavy metals, and other hazardous environmental pollutants [10, 11].

Among the common toxic heavy metals associated with petroleum, a total of eight metals identified in oil desalting wastewater include mercury, lead, arsenic, cadmium, copper, chromium, nickel, and zinc [12]. The volume of wastewater from desalination plants is very high so that for a daily production of 99.5 million barrels of oil worldwide, more than 50 million m^3 of water is considered. In fact, the average water-to-oil production ratio globally is three to one, and this ratio varies among different countries and depends on multiple factors, such as the age of the well, which causes this quantity to increase [13].

There are various methods to examine the environmental impacts of desalination projects and analyze the sustainability of desalination systems, one of which is life cycle assessment (LCA). The use of LCA is a supportive decision-making and management tool for evaluating environmental concerns [14, 15]. This method is to assess the performance and environmental burdens of processes and products, including goods and services, throughout their life cycle, encompassing the entire life cycle from raw material extraction and processing, manufacturing, transportation, and distribution to use, reuse, maintenance, recycling, and final disposal [16, 17].

In fact, this method quantitatively evaluates all resources consumed in the production of a product and all released materials to the environment, focusing on the least environmental impacts when selecting a product or process [18]. The effects of wastewater from oil desalination plants, despite their very high volume and severe pollution, have received little attention in previous research. These effects mainly concern oil-producing countries. Given the lack of a comprehensive understanding of the environmental impacts of desalination systems, it is essential to achieve a more precise and better understanding of the effects and various aspects of desalination processes.

Desalination Plant Operations Process

Desalting of crude oil occurs in two stages. This process depends on the characteristics and level of expected contamination after any pretreatment performed in the post-extraction phase from the well and after transportation from the extraction centers. Given the high amounts of salts and hydrocarbon sludge, water is used to dilute the crude oil. The crude oil, along with saline water, enters the desalting center and is directed to gravity tanks to settle the oil components.

The process includes mixing the heated crude oil with wash water and emulsion-breaking chemicals. Proper mixing is critical for salt removal and is achieved using mixing valves and static mixers. The emulsion is broken by a high-voltage electrostatic field in the gravity tank. The saline water phase, containing extracted salts and other impurities, is removed from the bottom. The excess saline wastewater from the process, which also contains high levels of salts and petroleum hydrocarbons, as well as other components, such as heavy metals and sulfur compounds, is transferred for injection into oil wells [12]. A schematic representation of the tanks in the desalination plant is shown in Figure 1.

The internal components of the electro-coalescing tank consist of stainless-steel electrodes, which are fed by high-voltage electrical converters. The oil discharged from the top of the electro-coalescing tank is directed by a pump toward the production unit, and from there, it is sent to the relevant centers for internal use or export. The settled saline water in the electro-coalescing tank is directed through connecting pipelines to the separator tank. However, if the saline water exiting the electro-coalescing tank has not yet reached saturation and is still usable, it is directed toward the return water tank for reuse. Figure 2 illustrates the path of incoming saline oil to the desalination plant and its output to the production unit [19].

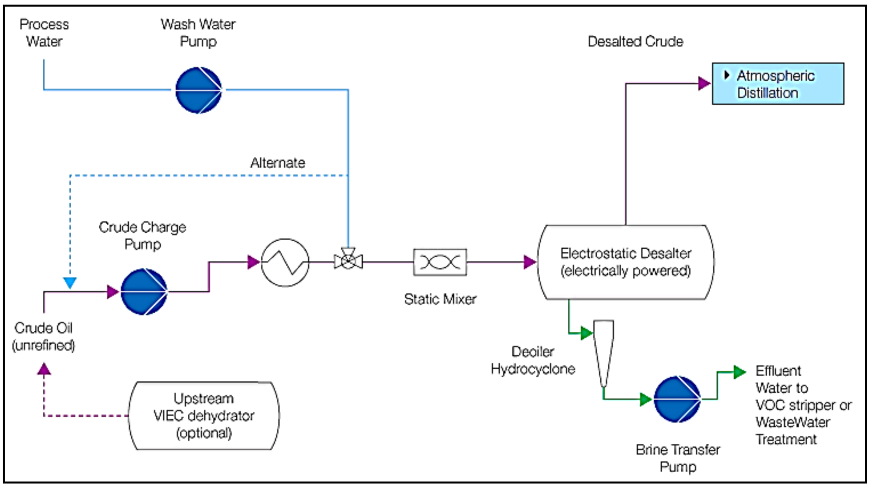

Figure 1. Schematic diagram of the tanks in a desalination plant and the injection of materials into them [12]

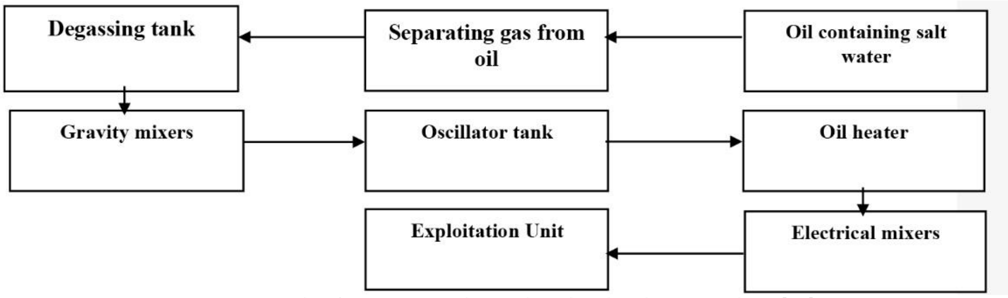

Figure 2. Path of incoming saline oil to the desalination plant [19]

The saline water flows down the separator tank in a spiral manner from the top of the tank. The oil separated from the water in this tank is collected from the top and directed to the surge tank. The separated saline water is sent from the bottom of the tank to the gravity separator tanks. In these tanks, the remaining oil particles are separated from the saline water, and ultimately, this saline water—referred to as wastewater—is filtered and entered into the wastewater storage tank. From there, it is pumped into underground wells for injection [20] In this desalination plant, 37,000 barrels of crude oil are processed daily. In this context, the LCA method has been applied to investigate this issue at the West Ahvaz desalination plant. In the present study, using the evaluation method and the Simapro9 software based on the ILCD 2011 Midpoint approach, the environmental impacts of the entire desalination process on various impact categories have been examined.

2. Materials and Methods

The present descriptive-applied research was conducted at a desalination plant in the southwest of Iran in 2023. The LCA of the crude oil desalination process was performed using Simapro9 software, taking into account the amount of wastewater generated during the process, along with the amount of materials and energy consumed and the output of the crude oil desalination process based on the ILCD 2011 Midpoint V1.03 method and its effects. The data used included information related to the input of the desalination systems (composed of oil and saline water), which encompasses heavy metals, total aromatic and aliphatic hydrocarbons, salt, and hydrogen sulfide, and the output amount of these materials after desalination. Additionally, data from existing databases in the software were utilized to catalog environmental impacts, specifically using the EcoInvent database.

In the next stage of the LCA, the Simapro9 software was employed. This software includes the four stages of LCA and several databases that comprise secondary data for hundreds of different types of products and services. Based on a series of influential components and specified standards within the Simapro9 software, pollutants and critical points in treatment plants were identified. Using this software, the LCA was systematically and transparently modeled in accordance with ISO 14040 standards.

Functional Unit and System Boundary

Every LCA study has a goal and scope, functional unit, and system boundary. The functional unit for this LCA is the production of one barrel of crude oil and the associated environmental impacts based on the excess wastewater produced for each barrel of crude oil produced at the desalination plant. The system boundaries are defined to encompass the process units relevant to the LCA [21]. The system boundary also includes the input lines at the desalination plant (the entry of crude oil extracted from the oil well) to the transmission lines of the desalinated oil.

Data Collection (Detailed Input and Output Analysis)

Data collection for quantifying the inputs and outputs of the system, as defined in the study's objective, was conducted through on-site visits to the oil desalination plant. The energy and system inputs and outputs were calculated for the LCA. Ultimately, the information related to pollution emissions and consumption was included in the list of global impact indicators (e.g., global warming, ozone layer depletion, toxicity, and carcinogenicity). The obtained data were analyzed using Simapro9 software and the ILCD 2011 Midpoint V1.03 method.

Life Cycle Assessment Based on the ILCD 2011 Midpoint V1.03 Method

The ILCD 2011 Midpoint V1.03 method is a framework developed by the European Union that supports the use of accurate characterization factors for impact assessment, as outlined in the ILCD guidance documents based in Luxembourg. This method is mid-point oriented based on impact assessment models and factors and includes 13 impact categories:

- **Global Warming:** Calculates radiative forcing over a 100-year timeframe.
- **Stratospheric Ozone Depletion:** Assesses the potential for ozone depletion over a 100-year period.
- **Human Toxicity and Cancer Effects:** Measures the toxicity and risk to human health per unit weight of emitted chemicals.
- **Human Toxicity without Carcinogenic Properties.**

- **Solid Particles:** Quantitatively assesses the impact of respiratory solid particles on premature mortality or disability in populations resulting from the emissions of SOx, NOx, and NH3.
- **Ionizing Radiation (impact on human health):** Evaluates the impacts of ionizing radiation on populations in comparison to Uranium 235.
- **Ionizing Radiation (impact on ecosystems):** Computes toxic units for ecosystems, primarily focusing on drinking water ecosystems.
- **Photochemical Ozone Formation:** Relevant only to the European database.
- **Acidification:** Assesses the excessive accumulation of characteristics that induce changes in critical and sensitive points in water toxicity of aquatic environments with the deposition of acidic substances.
- **Eutrophication of Land:** Similar to acidification, it concerns the deposition of substances that cause eutrophication.
- **Marine Eutrophication:** Refers to eutrophication in aquatic environments, specifically regarding nutrient emissions in marine settings.
- **Drinking Water Toxicity:** Calculates toxic units for drinking water [22]

Determining the Quantitative and Qualitative Characteristics of Produced Wastewater in the Crude Oil Desalination Process

The amount of saline water extracted along with oil in the oil extraction process from oil wells varies per barrel and depends on the type of well and extraction conditions. However, generally, for each barrel of oil extracted, between 50 and 80 liters of saline water is extracted as well [23]. This wastewater contains salts, oil sludge, heavy metals, and sulfur compounds, part of which is recognized as floating oil waste [24]. The total industrial wastewater produced by the oil desalination plant in Ahvaz is 1200 m^3 per day. The parameters measured in the wastewater and the standard methods for measuring these parameters are presented in Table 1.

Table 1. Methods, standards, and equipment for measuring physicochemical parameters of oil desalination wastewater

Test Case	Abbreviations	Std Test
Polycyclic aromatic hydrocarbon	PAHs	ISO 17993-GC/MS
Total suspended solids	TSS	ASTM D-5907-13
Sulfide	-	ASTM D 1339
Sulfate	-	ASTMD 4130-03
Calcium	Ca	D 511-03ASTM
Magnesium	Mg	D 511-03ASTM
Barium	Ba	ASTM D 3651-02
Strontium	Sr	ASTM D 5811-00
Iron	Fe	ASTM D 1068-05
Oil & Grease	O & G	ASTM D 3921-96
Hydrogen sulfide	H_2S	ASTM 427 D
pH	p-	pH-Meter –Metrohm 826
Turbidity	Tu	Turbidity Meter- HACH- 2100
Total dissolved solids	TDS	TDS Meter- TES 1381
Total Sulfur	TS	GC- Agilent-6890
EC	S	Conductivity Meter with USP 27
Heavy Metals	-	Atomic Absorption- EM900

3. Results

The first step in analyzing the impacts of wastewater production at the oil desalination plant unit in Ahvaz City using the LCA method involved assessing the physicochemical properties of the wastewater. The results of the physicochemical parameter measurements are presented in Table 2. Heavy metals are also significant pollutants in the wastewater from crude oil desalting processes. As observed, the values of total suspended solids (TSS), total dissolved solids (TDS), total sulfur, chemical oxygen demand (COD), and Oil and Grease in the wastewater sample significantly exceeded the EPA discharge standards. The results of measuring the amounts of heavy metals are presented in Figure 3.

The concentration of heavy metals measured in the wastewater samples from the desalination plant, as shown in Figure 3, indicates that magnesium, iron, nickel, and vanadium were present at average concentrations of 2.73, 2.52, 1.63, and 1.14 mg/L, respectively, surpassing other heavy metals in the desalinated wastewater.

Another critical component affecting the environment in crude oil desalting wastewater is polycyclic aromatic hydrocarbons (PAHs). Due to their physical and chemical properties, including non-polarity, chemical stability, and insolubility in water, PAHs accumulate in the environment. The measured concentrations of PAHs in the wastewater from the desalination plant are presented in Figure 4.

Table 2. Results of measurement of physicochemical components of desalination plant wastewater effluent

Test Case	Unit	Wastewater	US EPA discharge Standard
Total suspended solids	mg/L	1654	20
Total Organic Carbon	mg/L	231	-
Chemical oxygen demand	mg/L	752	125
Nitrate	mg/L	7.1	-
Phosphate	mg/L	2.5	-
Oil & Grease	mg/L	63	5
Hydrogen sulfide	ppm	1>	-
pH	-	6.3	6-8
Turbidity	NTU	82	75
Total dissolved solids	mg/L	121650	1200
Total Sulfur	%	0.78	0.5

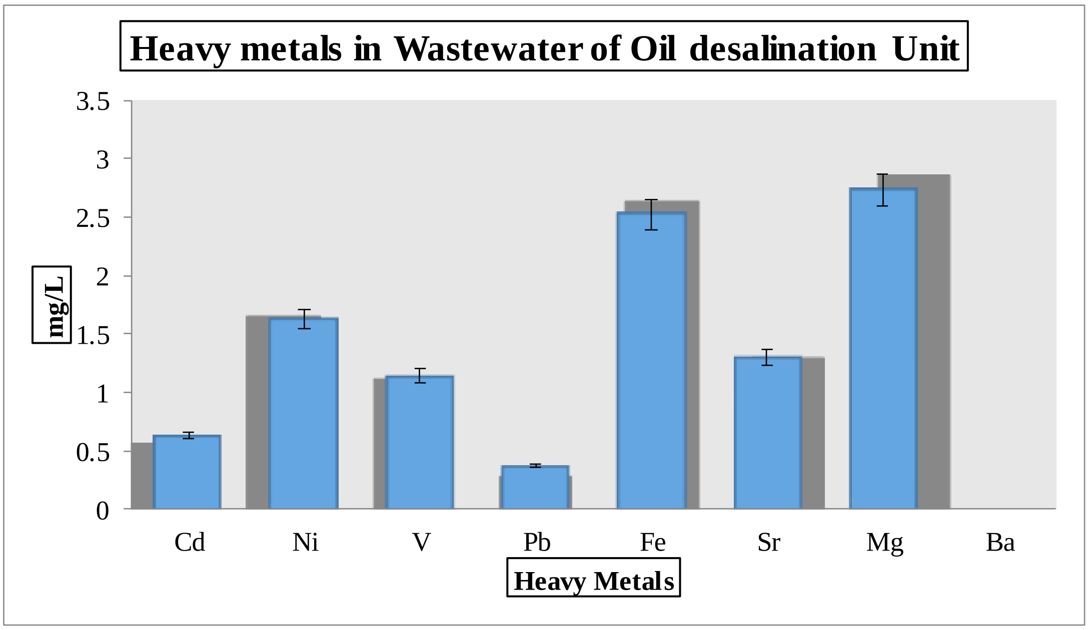

Figure 3. Results of heavy metal concentration measurements in wastewater samples from the desalination plant

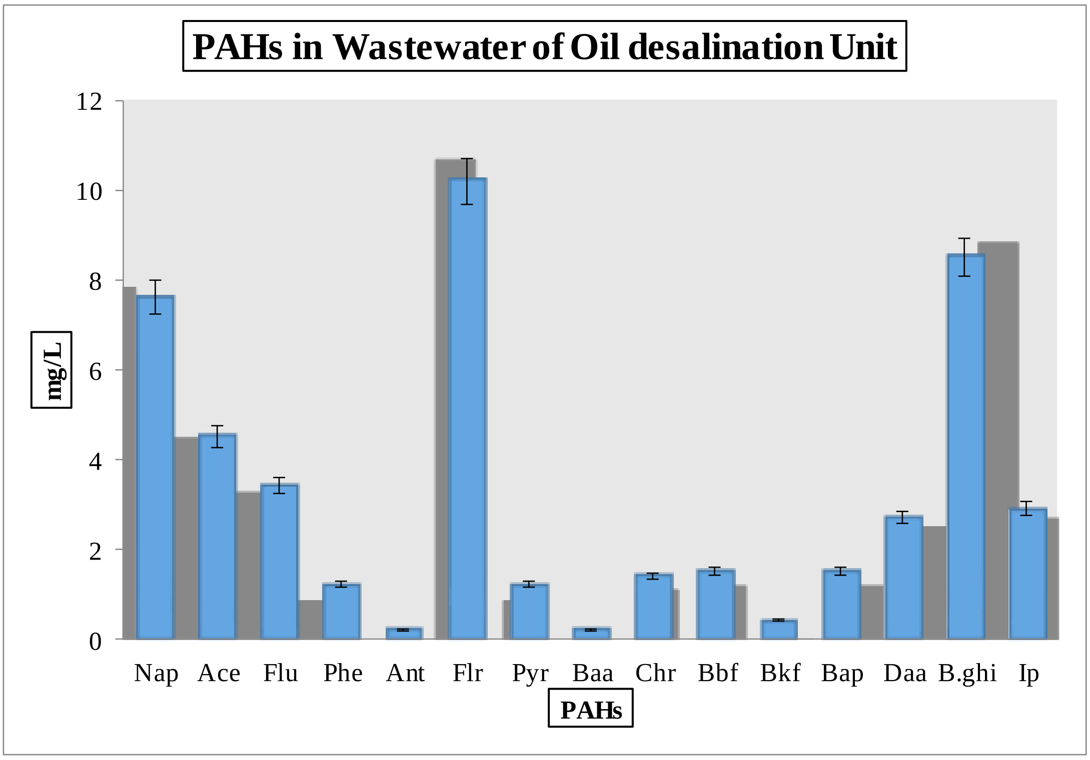

Figure 4. Distribution of PAHs concentrations measured in desalination plant wastewater samples

The results indicated that the concentrations of Fluoranthene, Benzo[g,h,i]perylene, and Naphthalene, with average values of 10.2, 8.5, and 7.6 mg/L, respectively, were among the most significant aromatic compounds with toxicity effects on humans and the environment found in the wastewater samples. Typically, PAH concentrations in most industrial wastewaters are in the microgram per liter range [25, 26]; however, in crude oil desalting wastewater, significant amounts of these compounds were measured in milligrams per liter due to the presence of substantial quantities of oil compounds.

A large portion of the oil compounds in wastewater is constituted by aliphatic compounds, which are generally considered to have lower toxicity compared to aromatic compounds. Following the determination of the quantitative and qualitative characteristics of crude oil desalting wastewater, the results of the LCA are presented.

Results of Life Cycle Assessment for Desalting Wastewater Using the ILCD 2011 Midpoint Method

In this method, the analysis of the subsets involved in the crude oil desalination processes is based on the total output of wastewater from the unit, assessed against the environmental impacts outlined in the ILCD 2011 method. The effects of eutrophication on the marine environment and ionizing radiation (HH and E) have been excluded from the categories. The results of the environmental impact assessment caused by the wastewater from the desalination plant using the ILCD 2011 method are presented in Figure 5.

The category of global warming impact assesses climate change related to the emission of greenhouse gases, specifically carbon dioxide, into the atmosphere. The results are estimated per production of organic compounds (COD, TOC, Oil and Grease, and PAHs). In the ozone depletion impact category, the measurement criterion is stratospheric ozone per produced chlorofluorocarbon. The toxicity impact category for humans and carcinogenicity is based on the risk level for humans. In this category, standards and permissible threshold limits provided by EPA, NIOSH, and ACGIH were used.

The acidification impact category can measure a pollutant's potential for acidification based on its capacity to produce positive hydrogen ions. In the eutrophication impact category, the effect of nitrogen and phosphorus on algal bloom phenomena is assessed. In the solid particulate impact category, particles smaller than 2.5 microns are used as the evaluation criterion. The land use impact category is also assessed in terms of kilograms of organic carbon deficiency in soils, while the formation of photochemical ozone is measured in kilograms of non-methane volatile organic compounds.

The impacts presented per functional unit in the life cycle of wastewater production in the crude oil desalination plant, which includes the production of one barrel of crude oil, have been evaluated. The assessment process was conducted using the SimaPro9 software environment. All the information entered into this software is based on the impact level of each factor in each impact category.

A comparison of the environmental impacts resulting from desalination plant wastewater using the ILCD 2011 method is presented in Figure 6. Soil acidification, at 22%, will be the most significant consequence of the life cycle of wastewater production on the environment. The acidification factor is attributed to the components of TOC (7%), COD (21%), H2S (14%), pH (36%), and PAHs (4%).

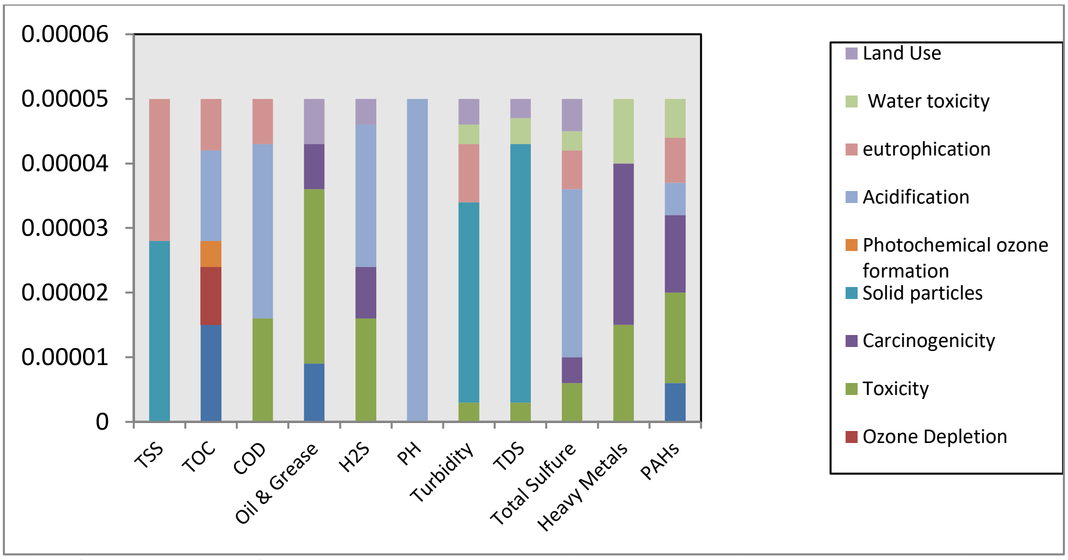

Figure 5. Results of the assessment of environmental impacts caused by desalination plant wastewater using the ILCD 2011 method

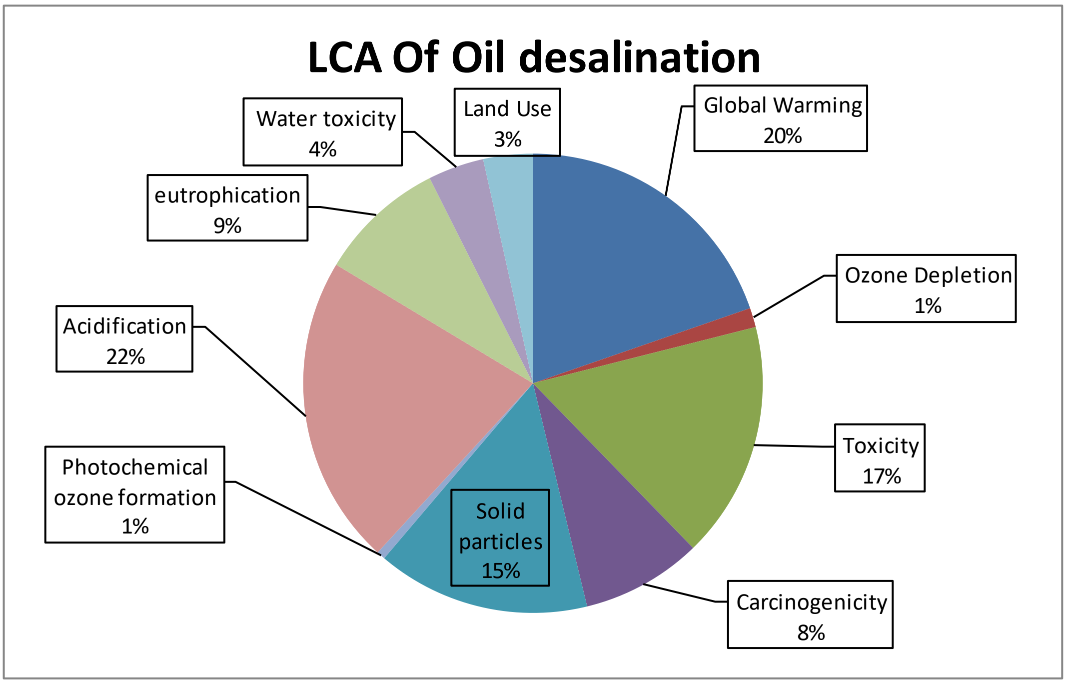

Figure 6. Comparison of environmental impacts caused by desalination plant wastewater using the ILCD 2011 method

In the global warming impact category, the greatest influences are related to TOC (57%), Oil and Grease (26%), and PAHs (17%). The main factor contributing to greenhouse gas emissions is energy consumption. Carbon dioxide is the most significant greenhouse gas produced during the process, formed through various reactions.

The effect of toxicity on humans and the environment, accounting for 17%, is the third most significant impact in LCA. Most factors have contributed to the creation of toxicity. However, based on the emission levels of compounds, Oil and Grease and aromatic compounds (38%), hydrogen sulfide (32%), heavy metals (25%), and total sulfur (5%) constitute the total toxicity effects resulting from the desalting process.

Solid particles, with 15%, represent the fourth most significant impact in the LCA of the crude oil desalination process based on the ILCD 2011 method. Particles generally contain various types of pollutants and toxic compounds, and if released into the environment, they lead to adverse effects and soil toxicity, which have the potential to transfer to humans. The components TSS (36%), TDS (34%), and turbidity (32%) are influential in causing this effect.

Carcinogenicity, accounting for 9%, is the fifth most significant environmental impact in the LCA of the crude oil desalination process. Heavy metals (65%), aromatic oil compounds (30%), and H2S (5%) have contributed to this impact.

The phenomenon of eutrophication, also at 9%, is the sixth environmental effect resulting from nitrate and phosphate compounds in the desalting wastewater. Water toxicity and land use also account for 4% of the other impacts resulting from the process.

4. Discussion

A review of various studies indicates that the discharge of wastewater from oil industries in developing countries faces more serious challenges compared to industrialized countries [27]. Low treatment technologies [28] and high costs of wastewater treatment before discharge [29] are among these challenges. According to the results of the present study, the levels of TSS, TDS, total sulfur, COD, and Oil and Grease in the wastewater samples exceeded the EPA discharge standards. Currently, in most oil-producing countries, the injection of desalinated wastewater into oil wells is a method to mitigate its environmental consequences. However, this method itself has significant consequences, such as equipment and pipeline corrosion due to high salinity, well clogging, the need for evaporation ponds, and the release of part of the wastewater into the environment (due to the very high volume) [30].

The study by Rahi et al. [31] revealed that the levels of TSS, TDS, and COD in refinery wastewater discharged into the environment in Iraq were 483%, 365%, and 194% above the discharge standards, respectively. Hale et al. [32] demonstrated that implementing active monitoring programs improved the wastewater treatment processes in the oil industry prior to discharge into the environment in Norway. The very high salinity and elevated levels of petroleum compounds, such as Oil and Grease and TPHs, indicate the high potential of this wastewater for environmental contamination.

Based on the results of heavy metal concentration measurements in desalting wastewater samples, the levels of magnesium, iron, nickel, and vanadium were higher than those of other heavy metals present in the wastewater. The study by Ismail and Beddri [33] indicated that the highest concentrations of heavy metals in refinery wastewater samples were related to iron and lead at levels of 3.16 and 2.89 mg/L, respectively. In another study, the highest concentrations of heavy metals in drilling rig wastewater included iron, nickel, and vanadium at levels of 12.5, 7.9, and 5.3 mg/L, respectively [34]. Adsorption, chemical oxidation, and biological degradation are the most effective methods proposed for the removal of heavy metals from oil wastewater [35]. Heavy metals primarily have toxic effects on humans and the environment.

Oil wastewater contains acidic chemical compounds, such as hydroxyls (OH), sulfates, and nitrates. The OH present in oil wastewater can react with the main components of soil to produce hydroxide ions (OH-). This ion can interfere with hydrogen ions (H+) present in the soil, leading to an increase in the number of hydrogen ions, which initiates the acidification of soil. On the other hand, the total sulfates and nitrates can also react with soil bacteria and microorganisms, disrupting the chemical composition of the soil, increasing soil erosion, and reducing soil fertility. Therefore, the most significant effect resulting from wastewater is recognized [36]. Considering the substantial effects of oil wastewater in the desalination plant, broader studies and the adoption of environmental management measures to mitigate the impacts are deemed essential.

5. Conclusion

The results of the present study indicate the extensive effects of the desalting process on the production of saline oil wastewater. Soil acidification, global warming, toxicity to humans, and the production of hazardous solid particles are among the most significant consequences of the oil desalination process based on the LCA method. The injection of this wastewater into oil wells is one of the methods currently being implemented in some oil wells in southwestern Iran. This study recommends conducting investigations into the potential for reusing this wastewater based on various usage scenarios using modern wastewater treatment methods.

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Authors' Contribution

Work methodology and final revision of the research: Fatemeh Karimi Organi

Main research method and life cycle assessment: Katayoon Varshosaz

Investigation of the chemistry of pollutants and their cycle on the environment: Haman Tavakkoli

Research analysis section guide: Neda Orak

Conducting various stages of research and final compilation: Ali Moltaji

Competing Interests

The authors declare that there is no conflict of interest regarding the publication of this manuscript. Furthermore, the authors have observed ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

Ethical Approval

This research obtained approval from the Research Ethics Committee of Islamic Azad University, Ahvaz, Iran (1063481197197400550191625849 4).

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References

1. Ossai, I. C., Ahmed, A., Hassan, A., & Hamid, F. S. Remediation of soil and water contaminated with petroleum hydrocarbon: A review. Environmental Technology & Innovation, 2020; 17: 100526. doi:10.1016/j.eti.2019.100526
2. Shafie, A., Fard, N. J. H., Monavari, M., Sabzalipour, S., & Fathian, H. Artificial neural network and multi-criteria decision-making methods for the remediation of soil oil pollution in the southwest of Iran. Modeling Earth Systems and Environment, 2024;10(1):417-424. doi:10.1007/s40808-022-01601-5
3. Rambeau, O., de Lafond, M. R., Baldoni, P., Gosselin, J. P., & Baccou, J. C. Low salt petroleum produced water reuse: a farming alternative outside the food chain. Water Science and Technology, 2004;50(2):139-147. doi:10.2166/wst.2004.0109
4. Scanlon, B. R., Reedy, R. C., Xu, P., Engle, M., Nicot, J. P., Yoxtheimer, D., ... & Ikonnikova, S. Can we beneficially reuse produced water from oil and gas extraction in the US?. Science of The Total Environment, 2020; 717: 137085. doi:10.1016/j.scitotenv.2020.137085
5. Jain, M., Majumder, A., Ghosal, P. S., & Gupta, A. K. A review on treatment of petroleum refinery and petrochemical plant wastewater: a special emphasis on constructed wetlands. Journal of Environmental Management, 2020;272: 111057. doi: 10.1016/j.jenvman.2020.111057
6. Warner, N. R., Christie, C. A., Jackson, R. B., & Vengosh, A. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environmental science & technology, 2013;47(20):11849-11857. doi: 10.1021/es402165b
7. 3akmakce, M., Kayaalp, N., & Koyuncu, I. Desalination of produced water from oil production fields by membrane processes. Desalination, 2008;222(1-3): 176-186. doi: 10.1016/j.desal.2007.01.147
8. Sharma, P., & Schiewer, S. Assessment of crude oil biodegradation in arctic seashore sediments: effects of temperature, salinity, and crude oil concentration. Environmental Science and Pollution Research, 2016;23:14881-14888. doi: 10.1007/s11356-016-6601-9
9. Philibert, D. A., Lyons, D., Philibert, C., & Tierney, K. B. Field-collected crude oil, weathered oil and dispersants differentially affect the early life stages of freshwater and saltwater fishes. Science of the Total Environment, 2019;647: 1148-1157. doi:10.1016/j.scitotenv.2018.08.052
10. Pichtel, J. Oil and gas production wastewater: Soil contamination and pollution prevention. Applied and Environmental Soil Science, 2016;2016(1). doi: 10.1155/2016/2707989
11. Sharma, K., Kalita, S., Sarma, N. S., & Devi, A. Treatment of crude oil contaminated wastewater via an electrochemical

reaction. RSC advances, 2020;10(4):1925-1936. doi:10.1039/C9RA09202A

12. Namdari, A., Roayaei, E., Jaafarzadeh, N., & Shariat, M. Measurement the significant heavy metals of Petroleum Desalination Influent in an Iranian on-shore desalination plant. Petroleum Science and Technology, 2017;35(7): 681-686. doi:10.1080/10916466.2016.1270302
13. Jafarinejad, S. A comprehensive study on the application of reverse osmosis (RO) technology for the petroleum industry wastewater treatment. Journal of Water and Environmental Nanotechnology, 2017;2(4):243-264. doi:10.22090/jwent.2017.04.003
14. Liu, Y., Lu, S., Yan, X., Gao, S., Cui, X., & Cui, Z. Life cycle assessment of petroleum refining process: A case study in China. Journal of Cleaner Production, 2020;256,:120422. doi: 10.1016/j.jclepro.2020.120422
15. Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinйe, J., Heijungs, R., Hellweg, S., ... & Suh, S. Recent developments in life cycle assessment. Journal of Environmental Management, 2009; 91(1): 1-21. doi: 10.1016/j.jenvman.2009.06.018
16. Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. Life cycle assessment. Springer International Publishing, Cham. Book. 2018. doi: 10.1007/978-3-319-56475-3
17. Simonen, K. (2014). Life cycle assessment. Routledge. link
18. Guinee, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., & Rydberg, T. Life cycle assessment: past, present, and future. Environmental Science & Technology. 2011;45(1):90-96. doi: 10.1021/es101316v
19. Karimi, A., & Rahimi Rashtabadi, Z. Assessment and Ranking of Environmental Risk Generating Activities in Ahvaz Desalination Plant No. 1 Using Analytic Hierarchy Process (AHP). Human & Environment, 2020;18(2): 1-15. link
20. Rajabi, H., Mosleh, M. H., Mandal, P., Lea-Langton, A., & Sedighi, M. Emissions of volatile organic compounds from crude oil processing–Global emission inventory and environmental release. Science of The Total Environment, 2020;727:138654. doi: 10.1016/j.scitotenv.2020.138654
21. Curran, M. A. Life cycle assessment: a review of the methodology and its application to sustainability. Current Opinion in Chemical Engineering, 2013;2(3): 273-277.doi:10.1016/j.coche.2013.02.002
22. Wolf, M. A., Kusche, O., & Dьpmeier, C. The International Reference Life Cycle Data System (ILCD) Format-Basic Concepts and Implementation of Life Cycle Impact Assessment (LCIA) Method Data Sets. In Environmental Informatics. 2011;pp. 809-817. link
23. Abdel-Aal, H. K., Zohdy, K., & Abdelkreem, M. Waste management in crude oil processing: crude oil dehydration and desalting. International Journal of Waste Resources, 2018; 8(1):1-4. doi: 10.4172/2252-5211.1000326
24. Pak, A., & Mohammadi, T. Wastewater treatment of desalting units. Desalination, 2008; 222(1-3):249-254. doi: 10.1016/j.desal.2007.01.166
25. Queiroz, R. N., Prediger, P., & Vieira, M. G. A. Adsorption of polycyclic aromatic hydrocarbons from wastewater using graphene-based nanomaterials synthesized by conventional chemistry and green synthesis: A critical review. Journal of Hazardous Materials, 2022;422: 126904. doi: 10.1016/j.jhazmat.2021.126904
26. Ilyas, M., Ahmad, W., & Khan, H. Utilization of activated carbon derived from waste plastic for decontamination of polycyclic aromatic hydrocarbons laden wastewater. Water Science and Technology, 2021;84(3): 609-631. doi: 10.2166/wst.2021.252
27. Radelyuk, I., Tussupova, K., Kleme , J. J., & Persson, K. M. Oil refinery and water pollution in the context of sustainable development: Developing and developed countries. Journal of Cleaner Production, 2021;302: 126987. doi:10.1016/j.jclepro.2021.126987
28. Jamaly, S., Giwa, A., & Hasan, S. W. Recent improvements in oily wastewater treatment: Progress, challenges, and future opportunities. Journal of Environmental Sciences, 2015;37: 15-30. doi: 10.1016/j.jes.2015.04.011
29. Abuhasel, K., Kchaou, M., Alquraish, M., Munusamy, Y., & Jeng, Y. T. Oily wastewater treatment: Overview of conventional and modern methods, challenges, and future opportunities. Water, 2021;13(7):980. doi: 10.3390/w13070980
30. Norouzbahari, S., Roostaazad, R., & Hesampour, M. Crude oil desalter effluent treatment by a hybrid UF/RO membrane separation process. Desalination, 2009;238(1-3):174-182. doi: 10.1016/j.desal.2008.01.045
31. Rahi, M. N., Jaeel, A. J., & Abbas, A. J. Treatment of petroleum refinery effluents and wastewater in Iraq: A mini review. In IOP Conference Series: Materials Science and Engineering. 2021;1058(012072):1-11. doi:10.1088/1757-899X/1058/1/012072
32. Hale, S. E., Oen, A. M., Cornelissen, G., Jonker, M. T., Waarum, I. K., & Eek, E. The role of passive sampling in monitoring the environmental impacts of produced water discharges from the Norwegian oil and gas industry. Marine Pollution Bulletin, 2016;111(1-2):33-40. doi: 10.1016/j.marpolbul.2016.07.051
33. Ismail, Z., & Beddri, A. M. Potential of water hyacinth as a removal agent for heavy metals from petroleum refinery effluents. Water, air, and soil pollution, 2009;199:57-65. doi: 10.1007/s11270-008-9859-9
34. Okoro, E. E., Okolie, A. G., Sanni, S. E., & Omeje, M. Toxicology of heavy metals to subsurface lithofacies and drillers during drilling of hydrocarbon wells. Scientific reports, 2020;10(1):6152. doi: 10.1038/s41598-020-63107-3
35. Raheem, A., He, Q., Mangi, F. H., Areeprasert, C., Ding, L., & Yu, G. Roles of heavy metals during pyrolysis and gasification of metal-contaminated waste biomass: a review. Energy & Fuels, 2022; 36(5): 2351-2368. doi:10.1021/acs.energyfuels.1c04051
36. Watmough, S. A., Whitfield, C. J., & Fenn, M. E. The importance of atmospheric base cation deposition for preventing soil acidification in the Athabasca Oil Sands Region of Canada. Science of the Total Environment, 2014; 493: 1-11. doi: 10.1016/j.scitotenv.2014.05.110