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Research Article

Water Footprint Reduction in Oil and Gas Refineries through Water Reuse: A Systematic Review

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Abstract

Oil and gas refineries are highly water-intensive industrial settings, with effluent containing a significant level of pollution stemming from diverse organic and inorganic compounds. Besides adhering to discharge standards for industrial effluent, incorporating treated oil refinery effluent (ORE) into the production cycle can play a pivotal role in curbing water consumption. In recent years, there has been research into different approaches to reclaiming ORE. Yet, selecting treatment methods that are technically, economically, and environmentally effective is crucial to preventing resource waste. Therefore, this study aimed to examine the last two decades of literature on methods and technologies used for ORE treatment. Based on the inclusion criteria, the final screening included 82 studies, with acceptable agreement assessed using Cohen's inter-examiner kappa equal to 0.86. The included studies were of biological treatment (n = 27), physicochemical processes (n = 12), advanced purification processes (n = 16), membrane-based technologies (n = 15), and green technologies (n = 13). This comprehensive review showed that the advanced membrane-based techniques are effective in the removal of pollutants from ORE for several reasons, such as reducing the consumption of chemicals, high efficiency, and ease of setup and maintenance. However, combined methods with a focus on membrane-based processes (e.g. UF-RO) are the most promising options for the reclamation of ORE. Since some effluent treatment methods require the use of chemicals and energy to run, future research should focus on environmentally friendly methods and the use of renewable energy.

Keywords

Oil Refinery Effluent, Reclamation and Reuse, Wastewater Treatment, Systematic Review

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1. Introduction

Sustainable water resources management, as a solution to address major concerns about water scarcity, maintaining sustainable growth in societies, and also the aim of creating ecological balance, is considered one of the important principles for achieving the Sustainable Development Goals (SDGs) [1, 2]. Moreover, water shortages along with increasing water demands, rapid demographic growth, the industrialization process, and rapid urbanization pose a great threat to future generations [3-5]. One of the solutions to conserve freshwater resources is the use of unconventional water resources (UWRs) as an emerging opportunity to solve water resource constraints, especially in water-intensive industries in arid and semi-arid regions, and subsequently overcome water scarcity [6, 7]. Unconventional water resources often require a series of advanced treatment processes, depending on the purpose of their use. Due to the limited access to freshwater resources (1% of the 2.5% of the planet's freshwater) and also the expensive costs of providing and treating freshwater and applying strict environmental regulations such as a green tax on effluent discharge, are reasons that encourage water-intensive industries such as oil refineries to supply part of their water consumption by using effluent reclamation treatment as a UWR. This can lead to the conservation of water resources and the reduction of freshwater consumption in refinery industries [8, 9]. Applying an appropriate and affordable treatment method not only provides an economical solution for the reclamation of oil refinery effluent but also alleviates water pollution and its human-related and consequent ecosystem challenges [10]. In the last two decades, several attempts have been made to introduce different oil refinery effluent reclamation technologies. Reclamation techniques are mainly based on biological treatment, physicochemical techniques, membrane-based processes (e.g., ultrafiltration, nanofiltration, reverse osmosis, etc.), coagulation either electrically or chemically, use of ion exchange systems, and hybrid systems including membrane-based processes in combination with ion exchange systems [1, 11-14]. Nowadays, the use of hybrid systems for the reclamation of industrial effluent with a focus on membrane-based processes has attracted many researchers [15, 16]. Numerous studies show that the membrane separation process is considered one of the main applied technologies for the reclamation of oil refinery effluent [17-19]. Compared to other conventional methods of industrial effluent treatment, membrane technology has the best prospects in effluent reclamation for several reasons, such as cost-effectiveness, a lower requirement of space and chemicals, and the high removal of suspended solids, colloids, and microorganisms [10, 20, 21]. On the contrary, dependence on environmental conditions such as temperature, oxygen level, variety of feed composition, and membrane scaling and fouling are among the disadvantages of membrane-based purification processes [1]. Nevertheless, due to the variety of organic and mineral pollutants, the discharge of oil refinery effluent without meeting environmental standards is a serious threat to the environment and public health [8]. Therefore, treating these effluents is a necessity, and reusing this treated effluent and returning water to the production and refining cycle, in addition to reducing freshwater consumption in refineries, will also help reduce environmental risks [22, 23]. We refrained from assessing studies focusing on traditional methods and procedures employed in oil refinery treatment plants, encompassing physical, chemical, and biological treatment of raw wastewater from various units, as it exceeded the scope of our study. Thus, through the integration of previous literature via a systematic review, this paper seeks to examine diverse effluent reclamation processes in oil refineries and select the most appropriate method considering technical, economic, and environmental aspects. Focusing on ORE treatment methods with the aim of reuse for various purposes is one of the interesting features that differentiates it from other studies.

2. Methods

2.1. Search Strategy

This systematic review was carried out to compile all available literature considering oil refinery effluent reclamation, focusing on the possible and/or potential applied methods and technologies that have been reported so far. The purpose of this study was to introduce, classify, and compare the used processes to give an outline for deriving the best option(s) for more detailed evaluations concerning the reclamation of oil refinery effluent from experimental to full scale. The study was carried out according to the PRISMA criteria and preferred reporting items for systematic reviews [24], and the flow chart is shown in Figure 1. The research was conducted between September 2023 and December 2023, and the databases searched to find the relevant articles were ELSEVIER (Scopus, Science Direct), SPRINGER, IWA, Taylor & Francis, and Taylor & Francis during the last two decades (from January 2002 to September 2023), and the literature searches were finalized on September 3rd, 2023. Using Advanced Search Builder, we have filtered only research articles published in English and selected the following keywords in the title and abstract: oil/petroleum refinery and effluent reclamation; oil/petroleum refinery and effluent recovery; oil/petroleum refinery and effluent reuse; oily effluent treatment and integrated processes; oil/petroleum refinery effluent treatment. The search terms used were used to combine keywords using Boolean operators, including "OR" and "AND," to match the various terms relevant to our review.

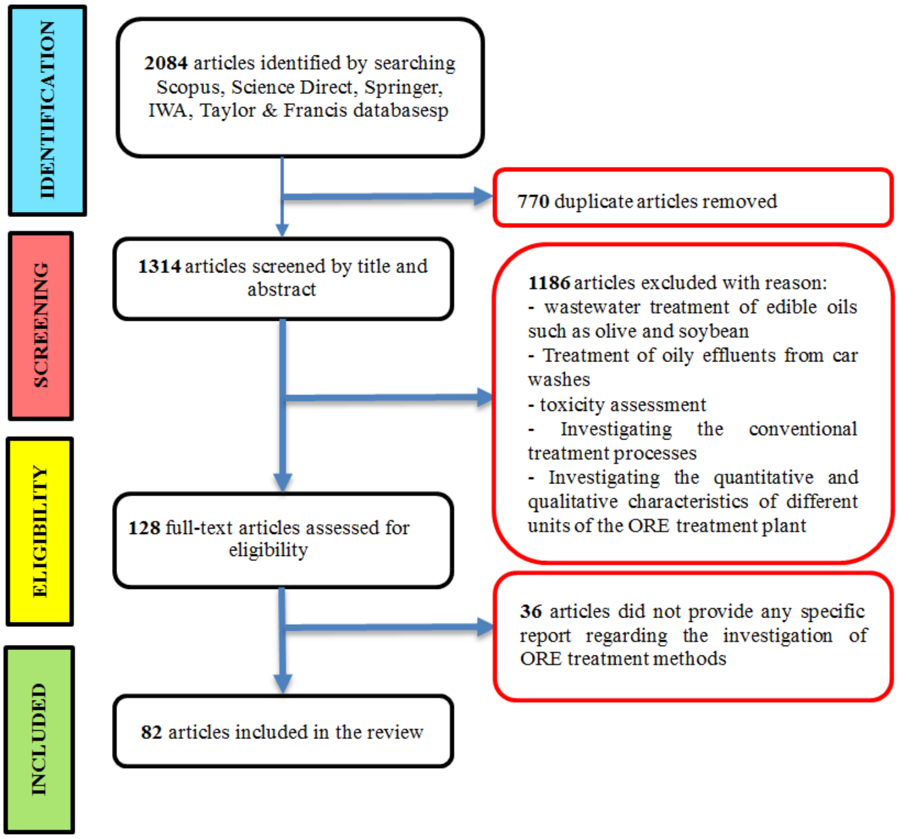

Figure 1. *Search flow diagram.*

2.2. Study Inclusion and Exclusion Criteria

The inclusion criteria included peer-reviewed publications in empirical and lab-scale on the various methods and processes of reclamation of oil refinery effluent, which were published in English. Exclusion criteria included reviews, guidelines, books, studies that were inaccessible in the full text, and studies not published between June 2002 and September 2023. In addition, the studies that were only conducted on the quantitative and qualitative characteristics of the oil refinery effluent and no treatment process was performed on them were excluded from the study. The four-step flow diagram in Figure 1 illustrates the number of studies that were included during the collection process based on inclusion and exclusion criteria.

3. Results

3.1. Background Data on the Included Studies in the Reclamation of Oil and Gas Refinery Effluent

In this study, based on a systematic search of the databases and additional resources, 2084 articles were identified, and 770 duplicate articles were removed, leaving 1314 articles. After screening the titles and abstracts, 1186 articles were excluded, leaving 128 articles. During the full-text screening of the selected articles (128 articles), 82 articles remained, and 36 articles were excluded.

3.2. Scattered Distribution of Literature

Figures 2, 3, and 4 show the distribution of studies conducted in the field of oil refinery effluent treatment by continents, countries, and different years. The continents of Asia (n = 44) and America (n = 19) have the most studies in the field of oil effluent treatment according to the criteria considered for entering the study between 2003 and 2023 (Figure 2). Among the 21 countries involved in this study, five countries, including Iran (n = 13 studies), Iraq (n = 11 studies), Brazil (n = 10 studies), India (n = 7 studies), and China (n = 7 studies), conducted the most investigations on the experimental and laboratory scales on the reclamation of oil refinery effluents. On the contrary, countries such as the UAE, Algeria, Egypt, Indonesia, Portugal, and Russia each had only conducted one study on the processes of treating petroleum effluent (Figure 3). The findings of the present study showed that during the last decade (between 2013 and 2023), more studies have been conducted than in the previous decade (2003 to 2012). Most studies were conducted in 2021 (n = 11 studies) and 2020 (n = 10 studies), and the fewest studies (1 study) were conducted between 2003 and 2008 (Figure 4).

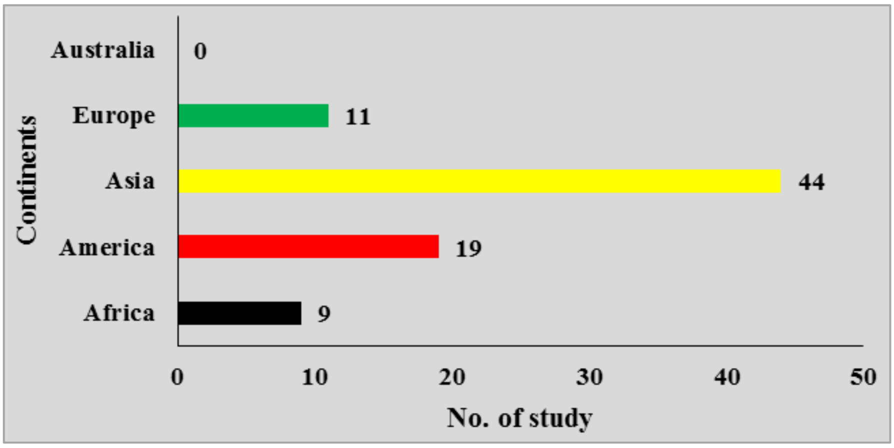

Figure 2. *Geographical distribution of the included studies by continents.*

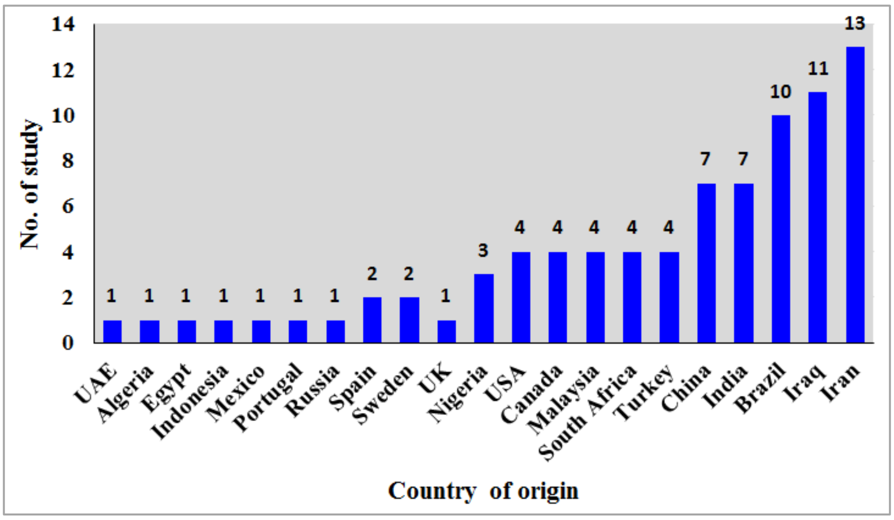

Figure 3. *Geographical distribution of the included studies by countries.*

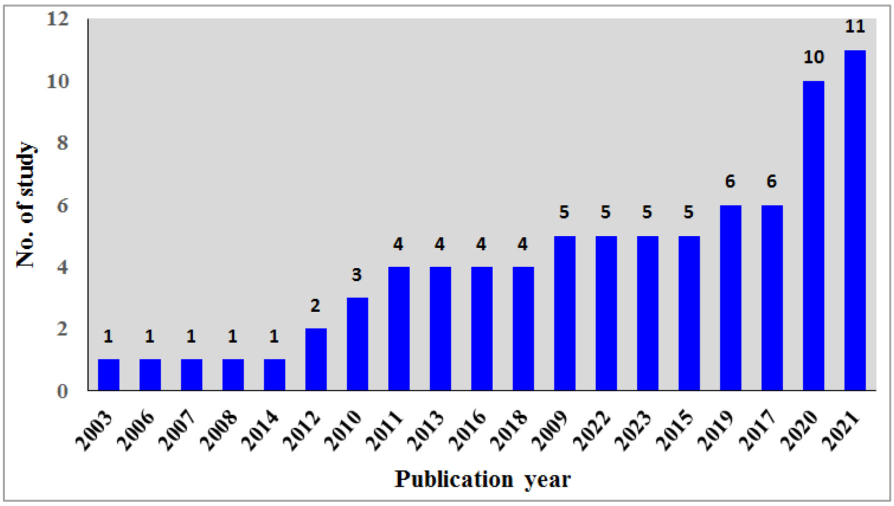

Figure 4. *The number of studies conducted in the last two decades (2003 to 2023).*

3.3. Oil and Gas Refinery Effluent Treatment Method

The oil and gas refinery effluent treatment processes were classified into five groups depending on the type of target pollutants to be removed from the effluent stream (Figure 5). The investigated methods include biological treatment methods (n = 27 studies), advanced purification processes (n = 16 studies), membrane-based treatment processes (n = 15 studies), green technologies (n = 13 studies), and physico-chemical processes (n = 12 studies).

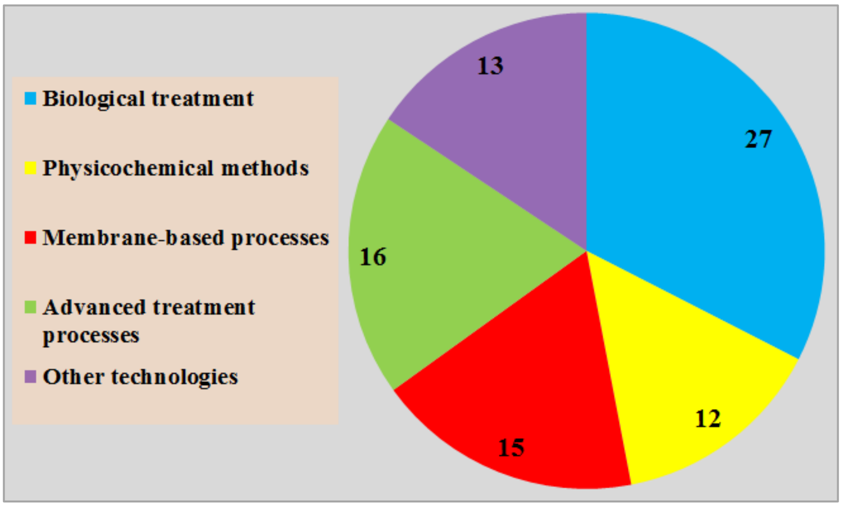

Figure 5. The number of studies based on the processes used in the reclamation of ORE.

4. Discussion

In this systematic review, our objective was to analyze recent literature concerning contemporary methods for reclaiming oil refinery effluent. These methods serve purposes such as water reuse and recycling across various units or ensuring compliance with effluent discharge standards to mitigate environmental risks.

4.1. Water Consumption in an Oil Refinery

Oil and gas refineries are one of the most important industrial process plants that refine petroleum into a wide range of different products [25]. The refining process uses a considerable volume of water. The water consumption rates a refinery uses largely depend on the types of processes that are performed. Approximately 246-340 L of water is needed for every barrel of crude oil. The lowest and highest amount of water is used in jet fuel refining units (0.09 gallons of water) and cooling towers to provide makeup water (50% of refinery water consumption), respectively [23]. The efficiency and management of operations in an oil refinery are to ensure the correct management of water consumption in different units. Effluent from various units can be treated for standard use or reuse, which in the long run saves a significant amount of costs related to freshwater supply [26].

4.2. Oil and Gas Refinery Effluent Treatment Methods

Depending on the nature and characteristics of the pollutants, different reclamation methods have been applied for the treatment of oil refinery effluent. Generally, oil refinery effluent treatment is handled by biological treatment, membrane filtration techniques, and advanced treatment processes (Figure 5). In biological treatment systems, anaerobic and aerobic units may be applied in the form of a secondary treatment process as a hybrid system or individually [27]. According to the presence of biodegradable organic compounds in oil refinery effluent, either biological or chemical systems can be applied as a secondary treatment. An anaerobic unit is utilized initially in effluent treatment systems to eliminate organic load when dealing with substantial amounts of organic compounds, followed by an aerobic unit (refer to Table 1). However, the presence of non-biodegradable compounds, recalcitrant compounds, and metals in oil refinery effluent poses significant challenges as these substances cannot be easily decomposed or removed through the aforementioned processes. Consequently, advanced treatment processes are necessary to meet discharge standards or enable the reuse of effluent for various purposes. These methods primarily involve membrane-based processes, either in hybrid configurations or separately, as outlined in Table 2.

4.3. Biological Treatment

Considering the variety of organic compounds such as COD, BOD, hydrocarbons, oil, and grease, it is necessary to use biological treatment methods to remove organic compounds from the oil refinery effluent. Among the biological treatment methods for the reclamation of oil and gas refinery effluents are bioremediation (use of microorganisms or microbial processes), biological absorption (use of plants and other adsorbents), membrane bioreactors, and aerobic and anaerobic reactors [28-33]. Some studies that used biological methods for the reclamation of ORE are listed in Table 1.

Table 1. *Oil refinery effluent reclamation using biological processes.*

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
MBR-PMR with TiO2	Removal of recalcitrant organic compounds	PMR with green TiO_2 and recycled membrane with high efficiency and stability in removing organic matter.	Brazil, [34]	2020
MBR on full-scale	Water supply required for Greenfields	MBR reduces the concentration of NH3-N to less than 0.5 ppm and reduces the potential for nitrification.	Brazil, [35]	2013
Sequencing batch reactor system	Removal of phenolic compounds	High effectiveness in removing total phenols around 98%.	UAE, [36]	2014
Anaerobic biofilm reactor (AnBR)	Removal of organic compounds	The significant relationship between system efficiency and bacterial diversity. The vital role of Acinetobacter and Pseudomonas bacteria in hydrocarbon degradation. Removal of COD by 80% after 11 days from the system launch.	China, [29]	2016
MBR on a pilot scale	Removal of organic compounds	MBR has high efficiency in removing COD, NH3-N, turbidity, color, phenol ,and toxicity and subsequently meets standards for disposal and reuse of non-potable water.	Brazil, [28]	2017
Biocathode microbial desalination cell (interaction of microalgae and bacteria)	Removing the organic compounds of ORE coupled with seawater desalination and bioelectricity production	Reduction of 70% COD, 81% BOD, 67% phosphorous, 61% sulfide, 67% TDS and 62% TSS. Save 1.245 kWh/m^3 of power by microbial desalination cell (MDC)	India, [37]	2020
Biological treatment using Tyrosinase Enzyme produced from different microbial strains	The degradation of toxic organic pollutants	Significant removal of 95% phenol and 89% PAHs in effluent.	Nigeria, [38]	2019
UASB-PBBR	Biodegradation of recalcitrant organic compounds (COD & PAHs)	COD removal efficiency in the UASB and PBBR over 118 days was 68.48% and 38.28%, respectively. Complete removal of PAHs.	Iran, [39]	2015
Anoxic–aerobic sequential moving bed reactors	Removal of hydrocarbon, phenol, sulfide, and ammonia-nitrogen	The optimum HRT of 16 h for complete removals of phenol, TPH, COD, and NH_3-N	India, [30]	2017
Submerged ultrafiltration system using hollow fiber (HF) polytetrafluoroethylene (PTFE)	The removal of total petroleum hydrocarbon	The removal efficiency of TPH was found to be more than 91%. Different fractions of petroleum and PAH	Iran, [40]	2023

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
membranes	(TPH)	compounds were reduced.		
Continuous flow microbial fuel cell (MFC) and packages of cells with serial and parallel flow connections	COD removal and electricity generation	At HRT 45 h, COD removal increased to 87% by increasing HRT. Open-circuit voltage (OCV) produced was 760 mV in parallel flow connections (PFC). COD removal in SFC (89%) and PFC (42%).	Iran, [41]	2020
Bioremediation (using Azolla pinnata var. imbricata)	Absorb Heavy Metals and Fluorides	A significant difference between the initial and final concentrations of metal ions and fluoride after using the Azolla plant. bioconcentration factor (BCF) of fluoride, zinc, cadmium, and iron ≤ 1 and BCF of lead, chromium, hexavalent chromium, and copper ≅ 1.	India, [12]	2015
Bioremediation: A Review	Removal of Petroleum Contaminants	Degradation of complex petroleum chemical pollutants into simpler forms using bioremediation (through microbes, plants, or biocatalysts (via enzymatic pathways), biosorbents (use of microbial biomass), or the use of biological products (natural fibers, composite biologicals).	India, [42]	2021
The use of Biosurfactants	Minimizing solid wastes	50 mg/l of rhamnolipid reduces sludge disposal by 52%, removes COD by 81-97%.	Brazil, [43]	2015
anoxic-oxic MBR on pilot scale	Removal of organic compounds	COD removal of 97.15 ±1.85%, while oil and grease removal at 96.6 ±2.6%	China, [44]	2018
UASB	Removal of organic compounds	In four organic volumetric loading rates of 0.58, 0.89, 1.21, and 2.34 kg/m3 d, COD removal was 78, 82, 83, and 81% respectively.	Malaysia, [45]	2012
Bioremediation (Photosynthetic bacteria) using effects of light intensity	Removal of pollutants and accumulation of high-value cell inclusions	500 lx was the optimal intensity for 62.66% SCOD and 91.54% NH_4^+-N removal. 4000 lx was the optimal light intensity for the carotenoid, bacteriochlorophyll, and biomass production	China, [46]	2021

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
UASB reactor using RSM	Removal of organic compounds	the effluent COD was 120 mg/L, the VSS effluent was 0.4 mg/L and the biogas rate was 0.025 L biogas/L feed.	Iran, [47]	2017
MBR	Removal of organic compounds	The use of oxalic acid at pH 2.5 followed by the use of NaOCl (5000ppm) increased the permeability of the membrane up to 92.7%.	Brazil, [48]	2021
Phytoremediation (using Brassica juncea) muskgrass (a macroalga, Chara canescens)	Removal of Selenium	Decomposition of all accumulated SeCN(-) into other forms of SeCN	USA, [49]	2002
Expanded Bed Nitrification	Nitrification	Biofilms incubated in ORE achieved higher ammonia removal than those incubated in the synthetic wastewater (SWW).	UK, [50]	2009
BAC	removing PAHs and aliphatic hydrocarbons	Removal of PAH by 97% under condition contact time (24 h), temperature (24 ℃), and moderate oxygen concentration (6–7 mg O_2 L^{-1})	Sweden, [51]	2009
UASB reactor	Removal of COD	76.3% COD removal efficiency and a 0.25 L biogas/L feed d biogas production rate	Iran, [52]	2011

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
Bioremediation	Removal of COD & BOD using Scenedesmus obliquus	Bioremediation is an effective technology in the reduction of pollutants like inorganic and organic compounds	India, [32]	2009
Batch biological reactor	Removal of COD, BOD, and Acute Toxicity	removal of 93% of BOD, 77% of COD, and 27.8% EC50	Canada, [53]	2002
Biosorption	Removal of Cr, Mn, Fe, Ni, Cu, and Pb metals	Maximum uptake of cationic metal ions at pH 4-6 by immobilized P. squamosus with fungal biomass	Nigeria, [33]	2007
Phytoremediation (using water hyacinth)	Removal of heavy metals	To overcome this limitation, factors such as pH, temperature, amount of water hyacinth, effluent flow and retention time, metal concentrations, and size of lagoon need also to be considered.	Malaysia, [54]	2008

4.3.1. Bioremediation and Biosorption

Bioremediation and biosorption are increasingly attracting attention for the treatment of industrial effluent, particularly oil refinery effluent, due to their capacity for photosynthesis, the generation of valuable products such as biofuels, and nutrient removal [55]. Additionally, utilizing plants (phytoremediation) as biosorbents to remove pollutants from oil refinery effluent is recognized as an environmentally safe and cost-effective method [12]. The presence of metals in discharged effluents from oil refineries is a notable health concern, potentially leading to environmental hazards if discharge standards are not met [56]. One of the methods of removing them is their biological absorption from the effluent stream. Some inexpensive adsorbents, including skin, chitosan, xanthate, zeolite, clay, peat moss, algae, dead biomass, etc., have shown high adsorption capacity for some pollutants, such as metals [54, 57]. For example, the results of the bioremediation of metals such as Cr, Mn, Fe, Ni, Cu, and Pb from the oil refinery effluent by calcium alginate-immobilized mycelia of Polyporus squamosus in a stirring bioreactor indicated a significant reduction of metals in pH 4-6 from the oil refinery effluent [33]. The examination of various literature sources revealed that the application of bioremediation and biosorption methods can significantly impact the elimination of pollutants from oil refinery effluents. These studies encompass a range of techniques, including the use of Scenedesmus obliquus microalgae to remove organic pollutants like COD and BOD, the utilization of water hyacinth and Azolla plants for heavy metal reduction via phytoremediation, the absorption of selenocyanate (SeCN) facilitated by Indian mustard (Brassica juncea) and musk grass (Chara canescens), the employment of photosynthetic bacteria such as Rhodopseudomonas and Pseudomonas under varying light intensities to eliminate organic pollutants like SCOD and NH4+-N, the degradation of toxic organic pollutants such as phenols and PAHs using the tyrosinase enzyme derived from different microbial strains, and the synergistic action of microalgae and bacteria in reducing organic compounds using biocathode cells [32, 37, 38, 42, 46, 58].

4.3.2. Membrane Bioreactor System

One of the compounds present in refinery effluents is the presence of phosphorus and nitrogen compounds such as ammonia in high concentrations, which can lead to a challenge called the nitrification process if discharge standards are not met. One of the methods to remove these compounds from the refinery effluent is the use of a membrane bioreactor (MBR) system, which, in addition to reducing other compounds such as COD, BOD, TP, turbidity, color, phenol, and oil and grease, can reduce nitrogen compounds, especially ammonia, below the output standard [28, 35]. The MBR system, in combination with other processes, is capable of reducing recalcitrant organic pollutants in oil refinery effluents. Oliveira et al. used a photocatalytic membrane reactor (PMR) coupled with MBR for the removal of recalcitrant organics from oil refinery effluent. The results of this research showed that the use of synthesized titanium dioxide nanoparticles (TiO_2) as a catalyst can decompose the resistant organic compounds in the effluent of the MBR system with a 60% efficiency, whose removal efficiency can be significantly increased by UV radiation. Furthermore, the membrane resistance when a catalyst was used was much higher than that of commercial membranes without a catalyst [34]. Based on the results of Santos et al.'s study, the preventive use of cationic polyelectrolytes leads to the improvement of sludge filterability as well as the reduction of membrane fouling caused by the accumulation of oil and grease in the bioreactor membrane during the regeneration of refinery effluents [59]. Also, various other strategies at the laboratory scale for cleaning MBR used in oil refinery effluent treatment, including the use of cleaning agents such as sodium percarbonate, dodecyl sulfate, citric acid, oxalic acid, and sodium hypochlorite in different concentrations, temperatures, and pH, were evaluated. Especially, oxalic acid (pH = 2.5) followed by NaOCl at a concentration of 5000 ppm more effectively removed organic and mineral deposits and subsequently increased the permeability at 40 ℃ by 92.7% [48].

4.3.3. Up-flow Anaerobic Sludge Blanket (UASB) Reactor

One of the methods of biological treatment of refinery effluents is the use of an anaerobic sludge reactor with flow (UASB), which can remove organic and resistant compounds from the effluent. These reactors, if combined with other processes, can increase the efficiency of removing pollutants from the effluent [52]. In a new method using a UASB reactor and an aerobic-bed biofilm reactor (PBBR) in the form of an anaerobic-aerobic hybrid system, Nasirpour et al. investigated the potential of biodegradation of hydrocarbons in oil refinery effluents, and the results indicate an 82% reduction of COD and complete removal of PAH [39].

4.3.4. Sequential Batch Reactor (SBR)

Among the other reactors for reducing the pollutants in the oil refinery effluent, it can mention the sequential batch reactor (removal of phenol), expanded bed bioreactor (for the nitrification process), sequential moving bed reactor (removal of phenol, sulfide, hydrocarbon, and ammonia-nitrogen), biologically activated carbon (BAC) system (for removing PAHs and aliphatic hydrocarbons), batch biological reactor (removal of COD, BOD, and acute toxicity), and anaerobic biofilm reactor (AnBR) [29, 30, 36, 50, 53].

4.3.5. Other Biological Processes

One of the methods of researchers' interest in the reclamation of refinery effluents is the use of microbial fuel cells (MFC), which, in addition to removing some organic compounds (COD), are also used to produce electrical energy. The results of a study using the MFC method showed that by increasing the hydraulic retention time (HRT) by 55.6 mW/m^2, energy production, and COD removal increased by 87% [41]. The use of biosurfactants with characteristics such as biodegradability, biocompatibility, and user-friendliness due to low toxicity is very useful for removing organic pollutants, reducing sludge volume, and increasing sludge sedimentation properties in the activated sludge process [43].

4.4. Membrane-Based Processes

Over the past two decades, membrane-based processes have proven to be extremely effective in removing and reducing pollutants from the aquatic medium, including effluent. Some studies that used membrane-based methods for reclamation of ORE are listed in Table 2. The main advantages of membrane-based processes are selectivity, no phase change operation, affordability, a smaller footprint, and ease of set-up and maintenance [9, 60]. Membrane-based processes are pressure-driven, and several types, including microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, have been employed in the water and effluent reclamation processes [1]. The review of the literature related to the application of membrane-based technologies in refinery effluent treatment showed that these processes are often used to recycle and reuse the treated effluent for applications such as providing makeup water for cooling towers and desalination units. Based on the characteristics of the effluent, membrane processes have been utilized individually, in conjunction with each other, and occasionally in hybrid configurations with non-membrane processes [22, 23]. One study examined and compared the viability of employing two membrane systems, forward osmosis (FO) and reverse osmosis (RO), separately, as well as a hybrid FO-RO system, for desalinating oil refinery effluent. Initially, FO and RO were employed as standalone processes, revealing that the RO process exhibited significantly higher efficiency in terms of permeation flux and effluent quality compared to the FO process. Furthermore, the study found that the FO-RO hybrid process was ineffective in effluent desalination due to limitations in the filtration unit [61]. In a study by Hosseini et al. investigating the utilization of a pilot-scale submerged ultrafiltration membrane (composed of polytetrafluoroethylene and hollow fiber) to reclaim seawater contaminated with petroleum products, the total petroleum hydrocarbon (TPH) removal rate was reported to be approximately 91%, with the oil content in purified water not exceeding 15 ppm [40]. Membrane-based processes find application in removing metals from refinery effluent streams as well [56]. A bench-scale assessment of membrane processes aimed at achieving acceptable mercury discharge limits in oil refinery effluent indicated that MF and UF membranes, operating at pressures of ≥2.8 bar, demonstrated high effectiveness in mercury removal. These processes successfully met the mercury discharge standard by reducing mercury concentration to <1.3 ng Hg/L. Moreover, NF and RO also proved capable of reducing mercury concentrations below the discharge standard when operated at lower pressures (20.7 bar). Nevertheless, RO and NF membranes, when used without pretreatment, proved ineffective in completely removing mercury from oil refinery effluent at higher operating pressures (≥34.5 bar). This inadequacy might be attributed to factors such as the deposition of mercury particles on the membrane surface under intense convection flow, leading to concentration polarization and a decline in mercury rejection rates [62]. An interventional experimental study was conducted to address metal removal from oil effluent through micellar-enhanced ultrafiltration (MEUF). UF membranes alone are unable to eliminate heavy metals (HMs), necessitating the use of surface-active agents, such as surfactants, to be injected into the effluent. The interaction between surfactant monomers and metal ions results in the formation of a complex, leading to the rejection of metal ions from the ultrafiltration membrane. The study's findings indicated an average removal rate of 94% for nickel, lead, cadmium, and chromium concentrations from oil refinery effluent [56]. Similar studies can be found involving membrane-based processes combined with other complementary processes. Hashemi et al. employed a hybrid system combining ultrafiltration (utilizing a hollow fiber polysulfane membrane) with a mixed bed ion exchange system to provide makeup water for cooling towers. The integrated process demonstrated an 80% efficiency in removing pollutants from oil refinery effluent and met the quality standards required for makeup water in the cooling towers [1].

Table 2. Oil refinery effluent reclamation using membrane-based processes.

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
UF-IX/MOX	Supply of makeup water for cooling towers	In the optimum pressure of 1 bar, removal efficiency of COD (57%), TDS (80%), Turbidity (94%), SiO_2 (67%), Oil (88%), and HPC (99%) was achieved.	Iran, [1]	2020
Comparison of hybrid UF-OMBR and MBR	oil refinery effluent treatment	The high removal efficiency for UF in UF-OMBR [COD removal (99.6)] compared to UF in conventional MBR [COD removal (66.8)]	Brazil, [63]	2019
FO using NaCl as the draw solute	Desalination	SO_4^{2-} rejection of 100%, CO_3^{2-} rejection of 95.66 ±0.32%, and flux recovery of 95% after CIP.	South Africa, [61]	2021
UF process	Removal of turbidity and mercury to meet the discharge standard	Removal of mercury less than 1.3 ppt and turbidity to less than 0.16 NTU.	USA, [64]	2013
Comparison of FO, RO, FO-RO Hybrid	Desalination of ORE to achieve effluent discharge standards	For FO (permeation flux: 3.64 ±0.13 L/m2 h, Cl-: 35.5, SO42-: 100%, CO32-: 94.59 ±0.32 and flux recovery of 86%. For RO (permeation flux: 2.29 ±0.24 L/m2h, Cl- rejection: 90.5%, SO42-: 95.1%, CO32-:97.3 ±0.4 and flux recovery: 62.52%. The FO-RO hybrid process proved unsuccessful	South Africa, [18, 65]	2021
Membrane desalination	Effluent desalination	In optimum conditions, final treated effluent by MD, the maximum amount of conductivity, COD, and chloride were 5.6 µS/cm, 4 mg/L, and less than 7 mg/L respectively.	Iran, [66]	2022
Membrane process	possibility to reuse the effluent as a makeup water	UF was more efficient in reaching the makeup water.	Turkey, [17]	2022
Nanofiltration membrane processes	water recycling, reuse, and product recovery: A review	NF was more efficient in ORE reclamation, recycling, reuse, and recovery applications due to its capability to separate the divalent/polyvalent ions while allowing permeation for monovalent ions and small molecules.	Malaysia, [67]	2022
Micellar-enhanced ultrafiltration (MEUF)	Removal of heavy metals	Ni, Pb, Cd, and Cr decreased by 96%, 95%, 92%, and 86%, respectively	Iran, [56]	2018
MF-RO	Removal of pollutants in petroleum effluents	MF-RO in the reclamation of ORE to supply water to steam boilers was efficient.	USA, [68]	2006

Table 2. *Continued.*

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
UF-NF	Removal of turbidity, COD, and Oil content, SO_4^{-2}, and NO_3	Removal of turbidity by 95%, COD (160 mg/l), Oil content (26.8 mg/l), SO_4^{-2} (110 mg/l), and NO_3 (48.4 mg/l) were agreed with the permissible limits of WHO. The Cl^{-1} (8900 mg/l) component was not within the allowable limits. This method is seen to be not sufficient to remove the salinity of the produced water.	Iraq, [69]	2016
UF (PS membrane)-RO (PA membrane)	Desalter effluent treatment	The UF membrane as an effective pretreatment removed more than 75% of the oil content, and RO removed more than 95% of TDS	Iran, [19]	2009
Membrane desalination	Removal of mercury	MF, UF, NF, and RO membranes were efficient in achieving the Hg discharge criterion (<1.3 ng/L). P≥34.5 bar had a significant effect on NF and RO flux and permeate quality.	USA, [62]	2012
Hybrid UF/RO membrane using polyacrylonitrile and polyamide membranes	Removal of oil and grease content, TOC, COD, TDS and turbidity	The hybrid UF/RO system reduced 100%, 98%, 98%, 95%, and 100% in Oil and G content, TOC, COD, TDS, and turbidity, respectively.	Iran, [70]	2011

4.5. Advanced Treatment Processes

Advanced effluent treatment methods encompass techniques that are more sophisticated and contemporary compared to secondary treatment processes. Nonetheless, over time, many advanced wastewater treatment processes have transitioned into conventional practices and are integrated into final treatment processes [71]. Currently, there is a growing utilization of these methods for effluent treatment. A review of the literature reveals that advanced oxidation processes (AOPs) and electrochemical processes are being employed in the reclamation of oil refinery effluent. Several studies utilizing advanced oxidation processes for oil refinery effluent reclamation are outlined in Table 3.

Table 3. *Oil refinery effluent reclamation using AOPs and electrochemical processes.*

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
Electrochemical oxidation using three-dimensional multi-phase electrode	Removal of COD, salinity, and phenol	Under optimum conditions (pH: 6.5; v:12V): Removal of COD by 92.8%, and salinity (84 µS cm^{-1})	China, [72]	2011
Electrochemical oxidation methods: using a boron-doped diamond anode, ruthenium mixed metal oxide (Ru-MMO) electrode, electro-Fenton, and electrocoagulation	Removal of COD, and phenol	Complete phenol and COD removal in almost all electrochemical methods, except electrocoagulation. The most efficient method: the electro-Fenton process followed by the electrochemical oxidation using a boron-doped diamond anode	Turkey, [73]	2010
Electrochemical oxidation using graphite anodes	Removal of COD, and phenol	Under best conditions (current density 12 mA cm^{-2}, pH 7, and NaCl: 2 gl^{-1}, and treatment time of 60 min): COD removal by 100% and phenol removal by 99.12%.	Iraq, [74]	2019
Batch ozone-photocatalytic oxidation (O3/UV/TiO2), and biological remediation by	Removal of phenol, sulfide, COD, O&G, and ammonia	the physicochemical results showed that a combination of (O3/UV/TiO2) for 10 min followed by macroalgae depuration seems	Brazil, [75]	2010

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
macroalgae		to be a good option for cost-effective treatment of produced water streams.		
Combination of AOPs (H2O2 photolysis and catalytic wet peroxide oxidation)	Removal of pollutants in petroleum effluents	H2O2/UVC process with LP lamp: removal of phenolic compounds, TOC, and COD was 100%, 52.3%, and 84.3%, respectively. Complete elimination of phenolic compounds, 47.6% of TOC, and 91% of COD was achieved during the H2O2/UVC process with an MP lamp.	Spain, [76]	2016
Electrocoagulation: RSM design approach	Removal of turbidity, TOC, COD, TDS, and Oil content	Removal of turbidity by 84.5%, COD by 82%, TDS by 20%, and Oil content by 99%.	Iraq, [11, 77, 78]	2023
Electrocoagulation Reactor Using Response Surface Method	Removal of TOC, Oil Content, and Turbidity	Removal of turbidity by 84.43%, TOC by 84%, and Oil content by 86%.	Iraq, [79, 80]	2020
Ozone-Based Advanced Oxidation Processes	Reuse and Recycle Solutions	↑ H2O2 amount to 80 mg/L, ↓ to 37.5 min →decreasing the energy and reagent consumption costs by 37%, reaching a final TOC under 4 mg/L.	Spain, [81]	2020

Table 3*. Continued.*

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
Electrocoagulation (EC) and electrochemical oxidation (EO) techniques	Removal of COD	EC (aluminum and mild steel were used as the anode): COD removal by 87% EO (ruthenium oxide-coated titanium (RuO2/Ti) was used as the anode): COD removal by 92%	India, [82]	2013
Electrochemical: using boron-doped diamond anodes	Organic compounds removal	The anode could be successfully used to treat effluents containing organic compounds. The anode (which was deposited onto a niobium substrate) was not stable and showed intense pitting corrosion after 300 h of use.	Brazil, [83]	2013

4.5.1. Advanced Oxidation Processes

Advanced oxidation processes (AOPs) serve in wastewater treatment to eliminate problematic organic substances and compounds that conventional methods struggle to decompose fully and effectively. Effluents subjected to tertiary treatment often contain low concentrations of both natural and synthetic chemicals, necessitating their removal or transformation into simpler substances to safeguard the environment and public health [84]. These processes may be employed individually or in combination with other techniques. The utilization of chemical processes alongside O3, H2O2, and UV for pollutant removal is referred to as an AOP [81]. Correa et al. employed O3/UV/TiO2 processes alongside biological remediation using macroalgae to eliminate phenol, sulfide, COD, O&G, and ammonia from petroleum refinery effluent. Their findings indicated that following a 5-minute treatment, the concentration of phenol decreased by 99.9%, sulfide by 53.0%, COD by 37.7%, O&G by 5.2%, and ammonia by 1.9%. Moreover, extending the treatment duration to 60 minutes resulted in increased efficiency in removing the investigated pollutants. Additionally, the biosorption and transformation of metals and ammonia compounds by macroalgae contributed to reducing the toxicity of the treated effluent [75]. The feasibility of multi-barrier treatment including filtration, hydrogen peroxide photolysis (H2O2/UVC), and catalytic wet peroxide oxidation for the treatment of oil refinery effluent with the aim of reuse or safe discharge was conducted by Rueda-Márquez et al. After the filtration step, turbidity and suspended solids decreased by 92% and 80%, respectively. During the H2O2/UVC process with low-pressure (LP) lamps at optimal conditions, the removal of phenolic compounds, TOC, and COD was 100%, 52.3%, and 84.3%, respectively. Complete elimination of phenol, TOC, and COD was achieved with medium-pressure lamps. Total TOC and COD removal after multi-barrier treatment was 94.7% and 92.2% (using an LP lamp) and 89.6% and 95% (using an MP lamp), respectively [76].

4.5.2. Electrochemical Processes

Electrochemical processes, including electrocoagulation (EC), electro-oxidation, electro-Fenton, catalyst-based processes, and electro-floatation, have various benefits, including easy distribution, environmental compatibility, selectivity, versatility, cost-effectiveness, reducing the use of chemicals, and energy efficiency [73, 82, 85-87]. In addition to these advantages, the need for experienced and specialized personnel for set-up and maintenance, corrosion on the surfaces of the electrodes due to chemical reactions subsequently limiting the performance, and a reduction in the life span are among the disadvantages of electrochemical processes [88]. In most oil refineries, coagulation using chemicals remains a common method for reducing turbidity and insoluble suspended solids. However, these methods come with various technical and practical limitations, such as the generation of significant amounts of sludge. Therefore, there is a need for a practical and efficient method for reclaiming oil effluents discharged from refinery units. Recent studies have highlighted electrocoagulation as an effective approach for effluent treatment [79]. This straightforward and efficient process offers a promising alternative to the chemical-intensive phases of traditional methods [89]. Electrocoagulation (EC) stands out as a simple method with several advantages over other processes, including the absence of chemical requirements and the need for expensive equipment. However, electrocoagulation (EC) also comes with several drawbacks, including the formation of oxide film, energy consumption, and generation of sludge (albeit less than that of chemical coagulation). Jasim et al. documented the complete removal of oil content from oil refinery effluent using a modernized electrocoagulation reactor (ECR). The study varied operating conditions such as electrolysis period (4–60 minutes), current density (0.63–5.0 mA/cm2), and flow rate (50–150 ml/min). Results indicated that increasing flow rate led to a decrease in oil removal efficiency while increasing density and electrolysis time improved efficiency up to 99% [11]. Similar studies have shown that employing the electrocoagulation process can reduce other pollutants in oil refinery effluent, with turbidity reduced by 84.5% [79], COD by 82% [77], and total dissolved solids (TDS) by 13% on average [78].

4.5.3. Electrochemical Oxidation

The electro-oxidation process involves generating oxidizing agents, such as hydroxide radicals, through the application of electric current [90]. This process decomposes pollutants in electric cells through two primary mechanisms: direct oxidation at the electrode and chemical reactions leading to the production of electron species and the generation of hydroxide radicals through chemical absorption [91]. It has been applied to remove and decompose industrial effluents containing dyes, oxygen, phenolic compounds, and other substances. A study conducted on the electrochemical oxidation process in a batch electrochemical reactor using graphite anodes for oil refinery effluent reclamation demonstrated that parameters such as current density (4–20 mA/cm2), pH (3–9), and NaCl concentration (0–3 g/L) significantly influenced the efficiency of COD and phenol removal. The results indicated that under optimal conditions (current density of 12 mA/cm2, pH 7, NaCl concentration of 2 g/L, and treatment time of 60 minutes), the removal efficiency for COD and phenol reached 100% and 99.12%, respectively [74]. In comprehensive research, the efficiency of some electrochemical methods was compared to treat the oil refinery effluent to remove COD and Phenol. In the study, the efficiency of different electrochemical processes including direct electrochemical oxidation by using a ruthenium mixed metal oxide (Ru-MMO) electrode, direct and indirect electrochemical oxidation by using a boron-doped diamond anode, electro Fenton, and electrocoagulation by using an iron electrode were investigated. In most of the studied electrochemical processes, nearly complete elimination of both phenol and COD was feasible, except for electrocoagulation, given that the electrolysis duration was extended. The most efficient process was electro-Fenton followed by electrochemical oxidation using a boron-doped diamond anode. COD removal of 75.71% was reached at 9 min of electrolysis in electro-Fenton, and Phenol removal of 98.74% was obtained at 6 min of electrolysis. Moreover, direct electrochemical oxidation achieved a remarkable 96.04% removal of COD and 99.53% removal of phenol. However, the effectiveness of the electrocoagulation method for treating oil refinery effluent was found to be lacking [73]. In a similar investigation focusing on the electrochemical treatment of oil refinery effluent containing organic compounds, employing a boron-doped diamond anode, it was observed that while the boron-doped anode exhibited high efficiency in effluent treatment, the efficiency of current (EC) and energy consumption were significantly influenced by current density and flow rate. Optimizing these parameters is crucial to minimizing EC for the method to be economically viable on a larger scale. Nonetheless, the stability of the boron-doped diamond anode was compromised due to severe pitting corrosion of the electrode [83].

4.5.4. Electrofenton Oxidation

Amongst electrochemical advanced oxidation processes (EAOPs), Electro-Fenton is a process in which two iron plate electrodes are used in contact with hydrogen peroxide, which is connected by connecting wires to a digital DC supply power device. According to the studies conducted, in addition to the iron electrode, electrodes such as boron-doped diamond (BDD), nickel alloy, titanium, rubidium, etc. can be used in this process to directly produce the desired radical without the direct intervention of H_2O_2 (Table 4). In this process, sodium hydroxide is usually used as an electrolyte to improve the ionic property and create the electrical conductivity of the effluent. Electro-Fenton oxidation is an environment-friendly and competent technique with energy capability, acquiescence to automation, high efficiency, and cost-effectiveness compared with other AOPs [92]. The findings show that using photovoltaic cell electro-Fenton oxidation for the reclamation of oil refinery effluent, it is possible to significantly remove organic compounds and recover oil content by 98% under optimal operating conditions, including a pH of 3, a reaction time of 25 min, a current of 1.63 mA, and a H_2O_2 concentration of 30 ppm [93]. A study was conducted on a small scale with constant monitoring of pH, temperature, and UV sources by Syarizan et al. In this study, due to no available tools to quantitatively determine the final concentration of phenol and benzene, one important assumption was that the degradation both of pollutants is directly related to the level of COD reduction. The parameters that were crucial to control optimal operating conditions included the Fenton reagent ratio, temperature, pH, reaction time, and UV irradiation. The results showed that, at the optimum ratio of Fenton Reagent (Fe: H_20_2=1:25), COD can be reduced up to 53.8%. Also, at the optimum temperature (40 ℃), COD can be reduced by up to 68%. It can be concluded that operating at a higher temperature increases the decomposition rate by 26% than operating at ambient temperature. Nevertheless, as there is no clear correlation between the degree of COD decrease and the rates of photo-degradation for the examined compounds, the results fail to provide a comprehensive evaluation of the overall effectiveness of the photo-Fenton process [92].

Table 4. *Oil refinery effluent reclamation using electro-Fenton-based and catalysts-based processes.*

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
Electrofenton process: using a porous graphite air-diffusion cathode	COD removal	COD removal efficiency: 94% with lowering specific energy consumption of 3.75 kWh/kg COD	Iraq, [86]	2023
Photo-catalytic system (TiO_2 and zeolite)	Removal of COD and SO_4^{2-}	Removal efficiency: 92% for zeolite and 91% for TiO_2, TiO_2 exhibited more efficiency in terms of mixing rate and reaction time requirements.	South Africa, [94]	2020
TiO2/Ag photocatalyst fixed on lightweight concrete plates	Removal and degradation of organic pollutants	COD removal under sunlight for 8 hours: 51.8% COD removal using UV-A lamps: 76.3%	Iran, [95]	2021
Photo-ferrioxalate and Fenton's reactions with UF step	Removal of pollutants	Removal of COD, phenol, sulfides, TSS, turbidity, and color, were 94%, <0.5 mg/L, <0.2 mg/L, <1 mg/L, 2 NTU, and 254 Pt-Co, respectively.	Mexico, [96]	2015
Photovoltaic cell electro-Fenton oxidation	Removal of organic compounds	More than 98% removal of organic content and 39.67 kWh/m^3 for the consumption of energy.	Iraq, [93]	2020
Nano-TiO2-Induced Photocatalysis	Removal of TPH	The use of solar light with doped TiO2 can replace UV light, which has a much higher energy consumption. Light-emitting diode light can also be an option because of its higher electron-photon conversion rate.	Canada, [97]	2017
Zinc Oxide Nano Particle as Catalyst in Batch and Continuous Systems	Removal of Oil content	Removal efficiency of the Oil content of the ZnO/UV was 80% at 20 mL/min and irradiation time 120 min.	Iraq, [98]	2021
Photo Fenton Reagent	Removal of Phenol and Benzene	The optimum ratio of Fenton Reagent is Fe: H_20_2=l:25, at a COD reduction of 53.8%. The optimum temperature for operating a photo-Fenton reaction is 40 ℃, at a COD reduction of 68%.	Malaysia, [92]	2004

Scenario	Purpose	Main results and conclusions	Country & Reference	Year
A semiconductor (ZnO, TiO2, and AL2O3) in the presence of solar as source of energy	Removal of oil content	Removal of oil content by ZnO, TiO2, and AL2O3 were 95.2 % and 92.11%, 80.7%, respectively.	Pakistan, [85]	2018

4.6. Other Technologies

Available technologies for the reclamation of oil refinery effluent have shown many advantages in oil content removal, but disadvantages include high operation and maintenance costs, chemical usage, secondary pollution, etc. [25]. Therefore, green and effective processes are greatly desired for treating oil refinery effluent. In recent years, the use of different types of catalysts individually or in combination with other processes has been investigated by experts in the field of water and wastewater [25, 85, 95, 99]. Photocatalysis has been widely employed in the removal of organic compounds and has proved to be affordable, low in selectivity, and efficient in terms of completed mineralization. Its efficiency has been accelerated by employing photoactive semiconductors such as nano-scaled titanium dioxide (TiO_2) [94, 98]. TiO_2 has proven that, in addition to its low cost, it has high stability and low toxicity towards both humans and the environment. Nano-scaled TiO_2 in different configurations, such as nanoparticles, nanotubes, and nanofibers, provides a great enhancement of photoactivity compared with bulk TiO_2 [100]. Nano-scaled TiO_2 has been employed to recover different types of onshore and offshore oil refinery effluent, targeting various compounds [101, 102]. Delnavaz et al. investigated the removal and degradation of organic pollutants from real oil refinery effluent using a TiO2/Ag synthesis photocatalyst immobilized on lightweight concrete plates (20×20×5 cm) and powered by 36-watt UVA lamps. The results of the effect of pH and mass loading on the system efficiency showed that at pH 4.5 and a mass load of 15 gr/m2, the removal efficiency reached its highest level. The rate of COD removal under sunlight in both states of using TiO_2 and TiO_2/Ag under optimum conditions was investigated. The rate of COD removal after 8 hours and the use of UV-A lamps for TiO_2 and TiO_2/Ag photocatalysts were 51.8% and 76.3%, respectively. The results found that the synthetic photocatalyst was able to treat real oil refinery effluent using UV rays [95]. The findings of another similar study that investigated the removal efficiency of oil content using three semiconductors of zinc oxide (ZnO), TiO_2, and aluminum oxide (Al2O3) showed that the adsorption of oil content on the supported catalytic agent was negligible in the absence of solar radiation. It was found that the removal of oil content by ZnO, TiO_2, and Al_2O_3 was 95.2%, 92.11%, and 80.7%, respectively, at pH 7.42 and 120 min of irradiation time. Furthermore, ZnO not only exhibits notable capabilities in adsorbing suspended solids (SS) and organic substances from oily effluent but also reduces the economic expenses associated with effluent treatment [85]. Another new method for the reclamation of oil refinery effluent in recent years is the use of nanocomposite materials and nanoparticles. Easy application, reusability, and a wide range of applications (ability to use for physical absorption, membrane processing, catalytic oxidation, and disinfection) are among the advantages of using nanocomposites. Conversely, drawbacks such as instability stemming from their cumulative nature, challenges in separating nanoparticles once they lose effectiveness (except for magnetic nanoparticles), and uncertainties regarding their environmental impact stand as disadvantages of nanoparticle utilization [103-105]. Types of nanocomposites can be categorized into organic nanocomposites (with polymer bases), inorganic nanocomposites (including active carbons, CNTs, and natural minerals such as zeolite, biochar, and clay), nanocomposite membranes [conventional membranes, thin film (used in RO/NF membranes), and membranes with surfaces covered with nanoparticles], and magnetic nanocomposites [104, 106]. Nanomaterial-based adsorbents, including metals or metal oxides at the nanoscale, carbon nanotubes, graphene, and nanocomposites, exhibit significantly greater absorption efficiency compared to traditional absorbents. This is attributed to their expansive specific surface area, heightened reactivity, and unique affinity towards diverse pollutants. For example, nanocatalysts with a high surface-to-volume ratio show much improved catalytic efficiency compared to their corresponding bulk materials. An investigation on the capability of magnetically separable Fe_3O_4/mordenite zeolite for the reclamation of oil refinery effluent considering the effect of parameters such as pH, contact time, and Fe_3O_4/mordenite zeolite amount on the COD, BOD, and turbidity was conducted. The findings showed that under optimum conditions (pH of 7.81, contact time of 15.8 min, and Fe_3O_4/mordenite zeolite amount of 0.52% w/w), pH was the factor affecting COD and BOD removal, and conversely, the amount of zeolite Fe_3O_4/mordenite had the greatest effect on turbidity removal [106]. The effect of cobalt ferrite nanocomposites as a photocatalyst for the oxidation of phenols in oil refinery effluent by Mohamed et al. was investigated. The results showed that using composite nanoparticles at a dosage of 0.5 g/l to 2 g/l at a pH of 3 and induced aeration, the highest degradation rate of phenolic compounds was achievable. Also investigated the recovery of the catalyst and the possibility of its sequential reuse. It was found that composite nanoparticle degradation ability decreased within a range of 5% during five cycles of reuse [107].

Limitations

This study possesses several constraints, with the most notable being the available evidence. Energy consumption is recognized as a drawback of effluent recovery techniques. Consequently, the examination of various literature sources revealed a scarcity of studies exploring the utilization of renewable energy to fulfill the energy demands for this purpose.

5. Conclusions

This study systematically studied the reclamation of oil and gas refinery effluent technologies and their efficiency in removing various pollutants from the effluent of this industry. In our study, almost all the various reclamation methods, such as membrane-base treatment, biological treatment, electrochemical processes, and advanced oxidation processes, were found to be very effective in the removal of pollutants from ORE. Based on the studies reviewed, membrane-based treatment systems can produce effluent of the same quality as drinking water, which is suitable for supplying water needed for boilers, cooling towers, and sanitary purposes. However, energy consumption and membrane fouling are the most important disadvantages of using membrane-based systems, which should be considered. From the mining of various literature, it seems that the combined methods are the most efficient option for the remediation of ORE. Nevertheless, in addition to the technical efficiency of effluent reclamation processes, parameters such as reducing the consumption of chemicals, using renewable energy, cost-effectiveness, and environmental friendliness should also be strongly considered. It is suggested that researchers do more research on 3R (Reduce, Reuse, and Recycle) and its applications in water-intensive industries such as oil refineries.

Abbreviations

AnBR	Anaerobic Biofilm Reactor
AOPs	Advanced Oxidation Processes
BAC	Biologically Activated Carbon
BCF	Bioconcentration Factor
BOD	Biological Oxygen Demand
CIP	Clean in Place
COD	Chemical Oxygen Demand
EAOPs	Electrochemical Advanced Oxidation Processes
EC	Electrocoagulation
ECR	Electrocoagulation Reactor
EO	Electro-Oxidation
FO	Forward Osmosis
HCs	Hydrocarbons
HF	Hollow Fiber
HPC	Heterotrophic Plate Count
HRT	Hydraulic Retention Time
IX	Ion Exchange
IXMB	Mixed Bed Ion Exchange
MBR	Membrane Bioreactors
MD	Membrane Desalination
MDC	Microbial Desalination Cell
MF	Microfiltration
MFC	Microbial Fuel Cells
MOX	Multi-Oxidant Disinfectant
NF	Nanofiltration
NH3-N	Nitrogen Content of the Ammonia
O&G	Oil and Grease
OCV	Open-Circuit Voltage
OMBR	Osmotic Membrane Bioreactor
ORE	Oil Refinery Effluent
PA	Polyamide
PAHs	Polycyclic Aromatic Hydrocarbons
PBBR	Packed-Bed BIOFILM reactor
PFC	Parallel Flow Connections
PMR	Photocatalytic Membrane Reactor
PS	Polysulfone
PTFE	Polytetrafluoroethylene
RO	Reverse Osmosis
RSM	Response Surface Methodology
SFC	Serial Flow Connections
SS	Suspended Solids
TDS	Total Dissolved Solids
TiO_2	Titanium Dioxide
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbon
UASB	Up-Flow Anaerobic Sludge Blanket
UF	Ultrafiltration
UWRs	Unconventional Water Resources

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Conflicts of Interest

The authors declare no conflicts of interest.

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