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Invited article

Recent improvements in oily wastewater treatment: Progress, challenges, and future opportunities

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ABSTRACT

Oily wastewater poses significant threats to the soil, water, air and human beings because of the hazardous nature of its oil contents. The objective of this review paper is to highlight the current and recently developed methods for oily wastewater treatment through which contaminants such as oil, fats, grease, and inorganics can be removed for safe applications. These include electrochemical treatment, membrane filtration, biological treatment, hybrid technologies, use of biosurfactants, treatment *via* vacuum ultraviolet radiation, and destabilization of emulsions through the use of zeolites and other natural minerals. This review encompasses innovative and novel approaches to oily wastewater treatment and provides scientific background for future work that will be aimed at reducing the adverse impact of the discharge of oily wastewater into the environment. The current challenges affecting the optimal performance of oily wastewater treatment methods and opportunities for future research development in this field are also discussed.

Introduction

Oily wastewater is wastewater mixed with oil under a wide range of concentrations. The oil mixed in water can be fats, hydrocarbons, and petroleum fractions such as diesel oil, gasoline, and kerosene. Nowadays, many industries generate a large amount of oily wastewaters, which have various adverse impacts on the surrounding environment, such as air pollution caused by the evaporation of oil and hydrocarbon contents to the atmosphere. In addition, they can affect groundwater, seawater, or drinking water as a result of the percolation of contaminants in produced water into the water resources beneath the soil. A variety of treatment methods geared toward the removal of the oil impurities can be used to minimize or avoid the adverse effects of oily wastewater. Examples are electrochemical treatment, membrane filtration, use of biological media, adsorption, flotation and chemical coagulation, treatment using ultrasound-dispersed nanoscale zero-valent iron particles, titanium dioxide, vacuum ultraviolet and natural minerals, and hybrid technologies, among others.

Electrochemical methods can be used to destabilize the emulsion of oil in wastewater through an electrical current. The most-used electrochemical methods in the treatment of oily wastewater are electrocoagulation and electroflotation. Membrane filtration involves the physical separation of the liquid content from a suspension *via* a membrane and through the application of pressure. The commonly used membranes are ultrafiltration (UF) and microfiltration (MF) membranes made of ceramic and polymeric materials. In addition, reverse osmosis (RO) membranes have been used in

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the treatment of oily wastewater. Biological treatment involves the use of microorganisms that produce the lipase enzyme, which breaks down the biodegradable organic substances in oily wastewater.

In the treatment of oily wastewater by adsorption, the oil is removed using adsorbents such as polypropylene, activated carbon, chitosan-based polyacrylamide. Furthermore, flotation and coagulation are two conventional methods applied for the treatment of oily wastewater. In the flotation method, the oil (having lower density than water) is removed by allowing it to float on the surface of water. In coagulation, the suspended solids, colloids, and oil particles are destabilized, so they begin to aggregate. As they aggregate to form bigger flocs, the density of the flocs becomes higher than the density of water and hence, the flocs settle down and are removed by sedimentation. It is noteworthy that the treatment of oily wastewater may be difficult and complex to accomplish with only one treatment method. The below sections highlight several contributions made by many scientists applying different treatment approaches.

1. Recent treatment approaches of oily wastewater

1.1. *Electrochemical treatment*

ectrochemical method is one of the most effective oily wastewater treatment techniques recently. Several electrochemical technologies have been applied to treat oily wastewater from different sources. These electrochemical technologies include electrochemical oxidation processes and electro-Fenton achieved using several electrodes. Electrode materials such as iron, aluminum, boron doped diamond, platinum–iridium, and titanium–rubidium have been tested. A summary of the treatment efficiencies of electrochemical technologies obtained in some works aimed at removing pollutants from different sources of oily wastewater is presented in Table 1.

Yavuz et al. (2010) investigated the treatment of petroleum refinery wastewater using three electrochemical methods: direct and indirect electrochemical oxidation using a boron-doped diamond anode; direct electrochemical oxidation using a ruthenium mixed metal oxide electrode; and electro-Fenton and electrocoagulation using iron electrodes. Their results showed that the electro-Fenton and electrocoagulation process using iron electrodes was the most efficient method, reporting 98.74% and 75.71% removal of phenol and chemical oxygen demand (COD) at 6 and 9 min respectively. Also, in direct electrochemical oxidation operating at 5 mA/cm^2, 99.53% and 96.04% removal of phenol and COD were reported respectively. Körbahti and Artut (2010) studied the influence of operating conditions (current density and reaction temperature) on the treatment and purification of bilge water using platinum–iridium electrodes in a batch electrochemical reactor. Their results demonstrated that a current density of 12.8 mA/cm^2 and 32°C reaction temperature removed 99.2%, 93.2%, and 91.1% of COD, oil and grease, and turbidity respectively with an average energy consumption of 33.25 kWh/kg COD removed. Also, Yan et al. (2011) investigated the effect of initial pH, cell voltage and applicability of using fine iron (Fe) particles in the treatment of petroleum refinery wastewater. Their results indicated that an electrochemical cell with a three-dimensional multi-phase electrode, which introduced Fe particles and air into a traditional two-dimensional reactor (Fig. 1), was very efficient in the treatment of petroleum refinery wastewater, as 92.8% COD removal and low salinity of 84 μS/cm were reported at initial pH of 6.5, cell voltage of 12 V, and addition of some fine particles of Fe.

Ngamlerdpokin et al. (2011) have compared chemical coagulation with electrocoagulation for the treatment of biodiesel wastewater, which was initially treated by acid protonation using three mineral acids, H_2SO_4, HNO_3, and HCl at different pH ranging between 1 and 8. The results showed that H_2SO_4 was very efficient for the removal of fatty acid methyl esters (FAME) and free fatty acids (FFA) at pH of 2.5 for 7 min. 24.5 mL/L of FAME/FFA was removed using H_2SO_4 while 15.1 and 21.2 mL/L removal was reported using HNO_3 and HCL respectively. Both chemical coagulation and electrocoagulation were effective in oil and grease removal, reducing the concentration from 105 to 80 mg/L. Moreover, the operating cost of chemical coagulation was 1.11 USD/m^3 compared to 1.78 USD/m^3 for electrocoagulation. Jaruwat et al. (2010) studied the management of biodiesel wastewater by chemical recovery using H_2SO_4 as a proton donor, with subsequent natural phase separation and electrochemical oxidation using a Ti/RuO_2 electrode. Their results indicated that biodiesel was recovered at 6%–7% (W/W) by a protonation reaction with H_2SO_4 at pH ranging between 2 and 6. Also, 87%–98%, 13%–24%, and 40%–74% removal of oil and grease, COD and BOD respectively were reported at low pH values.

Sekman et al. (2011) investigated the capability of electrocoagulation in the treatment of oily wastewater generated from port waste reception facilities using aluminum electrodes. They indicated that 98.8% removal of suspended solids was obtained at current density of 16 mA/cm^2 and electrolysis time of 5 min. In addition, 90% removal of COD was reported at current density of 12 mA/cm^2 and electrolysis time of 20 min. However, 80% removal of oil and grease was observed at all tested current densities after an electrolysis time of 10 min. Giwa et al. (2012) analyzed the treatment of petrochemical wastewater as affected by changing the values of current densities (7.55–21.64 mA/cm^2), the concentration of sodium chloride, NaCl (0.5–2 g/L), and electrolysis time (5–30 min). Their results showed that the ideal operating conditions that removed the maximum turbidity of 97.43% were 21.64 mA/cm^2, 2 g/L, and 30 min. El-Ashtoukhy et al. (2013) investigated the removal of phenolic compounds from petrochemical wastewater using electrocoagulation with a fixed bed electrochemical reactor. Their results determined a maximum removal of phenol (80%) at pH 7, NaCl concentration of 1 g/L, current density of 8.59 mA/cm^2, and at 25°C. Moreover, 100% removal of phenolic compounds was achieved after 2 hr with initial phenol concentration of 3 mg/L at the later obtained optimum operating conditions.

Ahmadi et al. (2012) have tried the addition of H_2O_2 and polyaluminum chloride in an electrocoagulation cell at different concentrations and doses. Their results showed that the oil and grease content was decreased from 11,781 to 4238 mg/L when the concentration of H_2O_2 and applied current density were at 2% and 10 mA/cm^2 respectively. On