Enhancing Industrial Wastewater Oil Removal Through Integrated Coagulation–Flocculation Pretreatment and Dissolved Air Flotation (DAF)

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Abstract
Oil content in the water that exceeds the threshold can pollute the environment if disposed of directly without waste treatment. This study conducted a case study of engineering waste treatment containing 1% oil using the Dissolve Air Flotation (DAF) method through coagulant and flocculant pre-treatment. The independent variable used in this study is pressure and residence time, where the pressure variable consists of 0.6, 0.8, 1, 1.2, and 1.4 bar, while the residence time variables comprised 5, 15, 30, 45, and 60 minutes. This study obtained the maximum pressure and residence time, namely at a pressure of 1.4 bar and a residence time of 60 minutes; the highest oil removal was 98.32%. Turbidity removal was 92.31% in 1% of engineering waste for engineering destruction.

***Keywords*:** *Coagulation, Dissolved Air Flotation (DAF), Flocculation, Oil Removal, Turbidity Removal, Wastewater Treatment.*

Abstrak
Kandungan minyak dalam air yang melebihi ambang batas bisa mencemari lingkungan jika dibuang secara langsung tanpa melalui proses pengolahan limbah. Penelitian ini dilakukan studi kasus pengolahan limbah rekayasa yang mengandung minyak 1% dengan menggunakan metode Dissolve Air Flotation (DAF) melalui pre-treatment coagulant dan flocculant. Variabel bebas yang digunakan dalam penelitian ini yaitu tekanan dan waktu tinggal, Dimana variabel tekanan terdiri dari 0,6 bar; 0,8 bar; 1 bar; 1,2 bar dan 1,4 bar sedangkan variabel waktu tinggal terdiri dari 5 menit, 15 menit, 30 menit, 45 menit dan 60 menit. Hasil dari penelitian ini didapatkan tekanan dan waktu tinggal yang

maksimal yaitu pada tekanan 1,4 bar dan waktu tinggal 60 menit didapatkan oil removal tertinggi sebesar 98,32 % dan turbidity removal sebesar 92,31% pada limbah rekayasa 1%.

Keywords*: *Koagulasi, Flokulasi, Dissolved Air Flotation (DAF), Oil Removal, Turbidity Removal, and Wastewater Treatment.

1. Introduction

The organic toxic waste harms aquatic life, plants, and animals and is carcinogenic and mutagenic to humans (Pintor et al., 2016). Among the many classes of pollutants, one regularly found in water and wastewater is “Oil and Grease” (O&G). Wastewater containing oil in various concentrations is referred to as oily wastewater. O&G is a group of organic substances whose defining characteristic consists of a very low affinity to water. Fats, hydrocarbons, and petroleum fractions like kerosene, gasoline, and diesel can all be found in water-mixed oil. The removal depends on the conditions of the oil-water mixture. The type of apparatus must be carefully chosen (Mohammed and Albarazanje, 2019; Pintor et al., 2016). The type of oil-water mixture may be categorized as free oil, dispersed oil, emulsified oil, or dissolved oil. Free oil is usually characterized by droplets greater than 150 microns. In comparison, a dispersed oil mixture has a droplet size range between 20 and 150 microns, and an emulsified oil mixture will have droplet sizes smaller than 20 micros (Mohammed and Albarazanje, 2019).

Oil in wastewater can be removed using well-known procedures. The kind of equipment must be carefully selected because the removal depends on the oil-water mixture's parameters. Several oil-water mixtures include dissolved, emulsified, disseminated, and free oil. Typically, droplets larger than 150 microns are used to identify free oil. By contrast, an emulsified oil combination will have droplets smaller than 20 micros, whereas a dispersed oil mixture will have droplets ranging from 20 to 150 microns (Muñoz-Alegría et al., 2021; Qi et al., 2013; Robinson, 2013; Wang, Jin, et al., 2021; Wang, Sun, et al., 2021).

DAF, or dissolved air flotation, is a dependable wastewater treatment technique. It has been used to treat fluids with various properties, including industrial water, wastewater, and drinking water. An emulsified oil mixture will have droplets smaller than 20 microns, and the mixture's droplet size ranges from 20 to 150 microns (Mohammed and Albarazanje, 2019; Muñoz-Alegría et al., 2021). DAF is a water treatment technique that removes suspended debris from wastewater to make it clearer. Air is removed by dissolving it under pressure in water or wastewater and then releasing it in a flotation tank at atmospheric pressure. Tiny bubbles release air, which sticks to the suspended stuff and causes it to float to the wastewater's surface, where skimming equipment may remove it. In order to meet environmental discharge regulations for turbidity, color, Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD), hybrid technologies have been integrated with the help of DAF's efficiency. Additionally, it has been used to remove small particles, oil, and grease. In recent years, DAF's technological growth has been made possible by its uses in wastewater treatment (Mohammed & Albarazanje, 2019; Muñoz-Alegría et al., 2021; Nasir et al., 2022).

The DAF technique is generally effective at treating water; it also has low operating costs and can be very appealing if it incorporates renewable energy sources into all operations. The methods commonly used to treat liquid waste are adsorption and filtration. The adsorption mechanism removes contaminants by adhering them to the surface of adsorbents (e.g., activated carbon). The adsorption is not effective for separating suspended solids or oils, and requires frequent regeneration or replacement of adsorbents, increasing operational costs. Another method is filtration. The filtration mechanism physically separates particles using a porous medium (e.g., sand filters, membrane filters). The filtrations limited effectiveness for removing fine particles or grease without pretreatment and the application of drinking water treatment, industrial cooling water, and pretreatment for desalination. The DAF technique is ideal for wastewater treatment applications requiring efficient removal of oils, grease, and fine particulates. It offers advantages in high-load scenarios where adsorption and filtration may struggle or incur high operational costs.

Chemical treatment of wastewater is carried out by coagulation/flocculation or coagulation-dissolved air flotation processes. These processes are extensively used in large-scale water treatment facilities and are preferable for treating wastewater from oil. The most widely used coagulants are iron salts, alum, and lime. These coagulants promote particle agglomeration by reducing the electrostatic particle surface charges in the acidic pH region where hydrolyzed metal species are abundant (Santo et al., 2012). This mechanism is usually combined with metal hydroxide precipitation and particle aggregation. However, adsorption continues during the neutralization process and can reverse the charge at colloidal surfaces, restabilizing the colloids. However, with the addition of excess coagulant, metal hydroxide flocks increase, and flocculation is enhanced. The efficiency of coagulation or flocculation depends on the coagulant dosage, pH, temperature, ionic strength, nature and concentration of organic matter, total dissolved solids, size and distribution of colloidal particles in suspension, and several other factors.

The pre-treatment of wastewater by coagulation-flocculation and DAF is necessary for wastewater clarification in various industrial facilities. DAF is applied to remove free and emulsified hydrocarbons from petrochemical and similar wastewater upstream from biological processes. It is also widely applied to treat industrial wastewater. Several researchers have reported efficient treatment of oily refinery wastewater by DAF (Al-Zoubi et al., 2015; Mohammed & Albarazanje, 2019; Nasir et al., 2022; Santos et al., 2021; Satpathy et al., 2020; Wang, Jin, et al., 2021; Wang, Sun, et al., 2021). In this work, a wastewater treatment using DAF, associated with coagulation and flocculation, has been coagulation and flocculation, has been investigated. A study used pre-treatment flocculation and coagulation methods to investigate the best oil content and turbidity removal from the wastewater treatment industry. The efficiency of coagulation or/and flocculation depends on the coagulant dosage, pH, temperature, ionic strength, nature and concentration of organic matter, total dissolved solids, size and distribution of colloidal particles in suspension, and several other factors. This work used polyaluminium chloride (PAC) as a coagulant because PAC mechanisms can neutralize charge. The aluminum ions in PAC can neutralize the negative charges on oil particles, enabling them to aggregate into large flocs. PAC can adsorb oil particles and other organic materials, stabilizing the flocs for easier removal. In industrial applications, PAC is often combined with other additives like polymers or flocculants to enhance oil-water separation efficiency in wastewater treatment processes. The anionic polyacrylamide (APAM), Arrad 3167, is used as a flocculant in industrial oil wastewater treatment due to its chemical and physical properties that facilitate the aggregation and settling of dispersed particles in water.

2. Method

2.1 Material

In this study, the material used was engineered wastewater containing lubricating oil in the form of used oil with a concentration of 1% dissolved in water in a volume of 50 liters and chemical concentration according to jar test results as the independent variable. It means to make engineering waste oil with a volume of 50 liters and a concentration of 1%, 0.5 liters of oil is needed and mixed into the waste storage tank. Softanol as an emulsifier, *polyaluminum chloride* (PAC) as a coagulant, and anionic polyacrylamide (APAM), Arrad 3167, as a flocculant. A jar test was conducted first to get the right dose for the concentration of coagulant and flocculant chemicals. In this work, the dependent variable is pressure in the saturator tank (0.6 – 1.4 bar with an interval of 0.2) and residence time (5 – 60 minutes with an interval of 15 minutes) in the DAF tank

2.2 Experimental Procedure

The oilfield produced wastewater samples from modified wastewater. The examples contained lubricating oil in used oil with concentrations of 1% dissolved in 50 liters of water. The sample was pretreated using coagulation and flocculation. Jar test analysis was carried out on waste sampling that had been made. This is done to find out the right dose of chemicals. **Figure 1** is the experiment procedure. The first is the feed tank with waste; the emulsifier input is *softanol* to flow in feed two and ensure the pH is neutral (7 - 8). Next, the coagulant input is PAC and circulated for 15 minutes. Then, the flocculant is anionic polyacrylamide (APAM), Arrad 3167, in feed tank two and circulated. The wastewater is filtered into the saturator tank, and the air is circulated from the compressor simultaneously. The pressure in the saturator tank is 0.6 to 1.4 bar (interval 0.2). Flow the wastewater from the saturator tank into the DAF tank. Retention times in the DAF tank are 5, 15, 30, 45, and 60 seconds. After that, the output from DAF is collected for oil content analysis (Eq. 1) and turbidity using a turbidity meter d density (Eq. 2).

$$\text{Oil and Fat} = \frac{(b-a)}{v} \times 10^6 \quad (1)$$

where: oil and fat are oil and fat content in wastewater (mg/l); a is the weight of empty porcelain in a cup (grams); b is the weight of the filled porcelain cup (grams); and v is the volume sample (ml).

$$\text{Density} = \frac{\text{final weight - initial weight}}{\text{solution volume}} \quad (2)$$

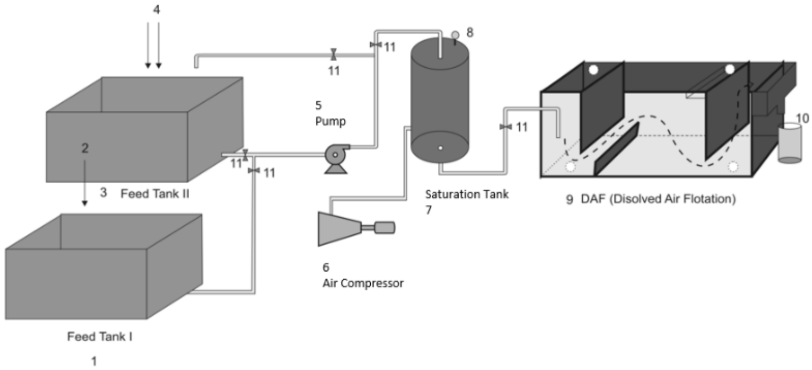

Figure 1. Process Flowsheet for Reducing Oil Content Using The DAF Method Through Pre-Treatment of Coagulation and Flocculation

3. Result and Discussion

The effect of the pressure based on retention time on %oil removal and the modified wastewater treatment using DAF, and the effect of pressure based on retention time on %turbidity removal. DAF outperforms water recovery in the industrial, agricultural, and domestic-municipal sectors. DAF uses microbubbles (MBs) to remove fine particles from the flow. Four steps are involved in conventional DAF: flotation, sludge removal, chemical processing of wastewater, and MB production. The technique's structural component is a float tank with a baffle between the contact and separation zones. The particles are guaranteed to collide and adhere to the MBs in the contact zone before being transferred to the separation zone. This MB-particle aggregation rises to the surface, forming a foam or sludge layer (Muñoz-Alegría et al., 2021).

3.1 Effect of Pressure Based on Retention Time on %Oil Removal

Pressure is one of the parameters determined by the DAF process to reduce the oil content of engineering waste through coagulation and flocculation pretreatment. To facilitate the discussion of this research, the following **Figure 2**:

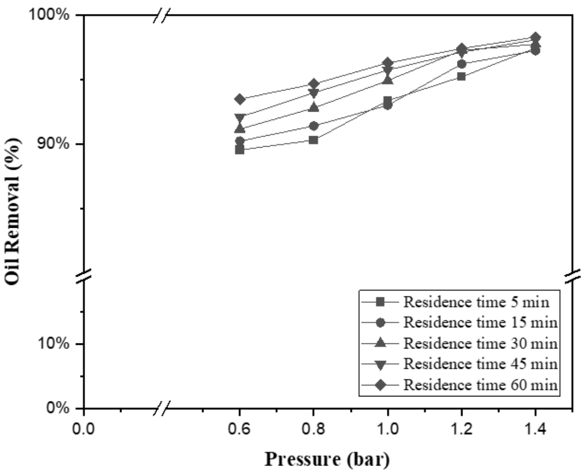

Figure 2. Effect Pressure Based on Retention Time Variation at a Wastewater Concentration of 1% on %Oil Removal

Figure 2 shows the relationship between the percentage of oil removal and pressure at a concentration of 1%, which obtained the best percentage of oil removal at 98.32% with a pressure of 1.4 bar. The higher the operating pressure, the higher the percentage of oil removal in the engineering wastewater in the effluent. This is because the greater the pressure, the more air enters the water, so the dissolved air in the water increases. When wastewater containing dissolved air is released to atmospheric pressure, the water's dissolved air molecules will be released into very fine bubbles. The greater the pressure given, the more and smaller the bubbles produced. These bubbles will rise to the water's surface while carrying suspended organic compound particles. This process causes the oil content in the wastewater to decrease, and the water becomes clearer, increasing the percentage of oil removal (da Silva et al., 2015; Pintor et al., 2016; Qi et al., 2013). At a pressure of 0.6 bar, the reduction of oil removal in wastewater is less effective; this is because the air pressure provided is not maximal; as a result, when the water in the flotation tank is released to atmospheric pressure, the air bubbles produced are very small in number and large in size. The large size of the bubbles in a small amount is certainly not effective in lifting organic or inorganic particles contained in engineering waste (Mohammed and Albarazanje, 2019; Okiel et al., 2011; Wang, Jin, et al., 2021). Pressure, retention time, and oil removal in relation to the ideal pressure range. Efficiency may be reduced by pressure above or below the ideal range. While too high of a pressure can cause turbulence or inefficient flotation, too low might not produce enough bubbles. In addition to decreasing air solubility, the lower pressure also reduces the population of microbubbles, which reduces the efficiency of oil removal by preventing bubbles from colliding with oil particles (Wang, Jin, et al., 2021). Retention time has an impact; if it is too short, microbubbles won't have enough time to adhere to oil particles and rise to the top, which will result in less oil being removed (Wang, Jin, et al., 2021; Wang, Sun, et al., 2021). Reduced phase-to-phase interaction from faster throughput can be crucial in high-flow applications. If a lengthy retention period offers ample time for bubble-oil interaction, floc flotation, and the successful collection of separated oil at the surface. In high-throughput systems, an extended retention period can result in operational inefficiencies or oil re-entrainment.

3.2 Effect of Pressure Based on Retention Time on %Turbidity Removal

The effect of coagulant type on turbidity removal was also investigated in the present study. The experiment used pre-treatment coagulation and flocculation methods. *Polyaluminum chloride* (PAC) is a coagulant, and Arrad 3167 is a flocculant. **Figure 3** shows that the best turbidity removal percentage occurs at a pressure of 1.4 bar at a concentration of 1% engineering waste capable of achieving up to 92.31% turbidity removal. This occurs because, at a pressure of 1.4 bar, the turbidity removal percentage value produced by the saturator tank is sufficient to float particles that cause turbidity to the surface of the liquid. In a study conducted by (Wang, Jin, et al., 2021) with pH variables and coagulant doses operating at a pressure of 600 Kpa, a maximum turbidity reduction efficiency of 70% was obtained. Turbidity is a measure that uses the effect of light as a basis for measuring the condition of raw water with a scale of *Nephelometric Turbidity Unit* (NTU), *Jackson Turbidity Unit* (JTU), or

Formazin Turbidity Unit (FTU); the presence of mixed objects or colloidal objects causes this turbidity (da Silva et al., 2015; Santos et al., 2021). Water turbidity can be caused by the presence of inorganic and organic materials contained in water, such as mud and materials produced by industrial waste. Still, in this study, turbidity was caused by oil waste dissolved in water. The greater the content of suspended particles in the liquid, the greater the turbidity value.

Effective turbidity and oil content removal is ensured by the ideal ratio of pressure to retention time. For instance, stable microbubbles that efficiently interact with flocs are created by moderate to high pressure and sufficient retention time. The quality of the flocculation and coagulation pretreatment significantly impacts the DAF process' efficacy. The flocs are hydrophobic enough to adhere to the bubbles when coagulants and flocculants are dosed correctly, enhancing turbidity removal. The pressure in a DAF system influences the solubility of air in water and the release of microbubbles during the flotation process.

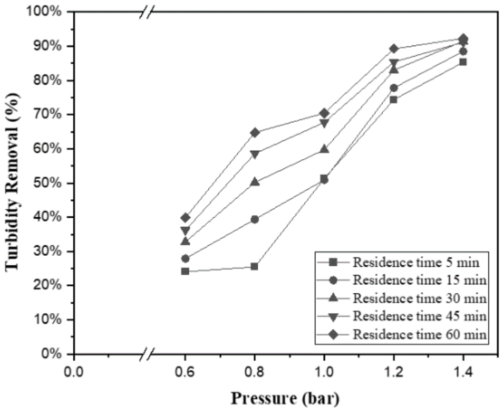

Figure 3. Effect Pressure Based on Retention Time Variation at a Wastewater Concentration of 1% on %Turbidity Removal

Generally speaking, higher pressure promotes the development of smaller bubbles, which strengthens floc and oil droplet attachment to the bubbles and facilitates separation. Larger bubbles and ineffective floc attachment can result from low pressure, which can further decrease the effectiveness of turbidity removal. Excessive pressure in high pressure may result in operational inefficiencies, such as reduced bubble stability, and may not significantly improve turbidity removal. At optimal pressure, adequate microbubble formation guarantees high interaction with flocs, resulting in effective separation and a higher percentage of turbidity removal (Wang, Jin, et al., 2021; Wang, Sun, et al., 2021).

4. Conclusion

This work successfully applied the dissolved air flotation (DAF) associated with coagulation and flocculation pretreatment samples to oilfield wastewater treatment. The confirmatory result of the optimal residence time in the most effective DAF is 60 minutes. The highest percentage of oil removal was 98.32%, and the percentage of turbidity removal was 92.31% at 1% waste concentration after pre-treatment. The DAF systems can significantly improve oil and grease removal from industrial wastewater. This makes them ideal for refineries, petrochemical plants, and food processing industries dealing with oil-rich effluents. Implementation in existing treatment plants can improve compliance with strict environmental regulations, such as reducing Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). Recommendations for further research include optimizing operational parameters to investigate the effects of pressure, saturation time, and air-to-water ratio on oil removal efficiency for various types of industrial wastewater. Second, advanced coagulation/flocculation techniques to explore the use of innovative coagulants or bio-based flocculants to improve the separation of emulsified oil in DAF systems.

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