Exploring the Efficacy of Ulva lactuca in Industrial Wastewater Treatment: A Sustainable Approach

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Abstract:- The toxic and persistent organic and inorganic elements in oil refinery effluents, such as heavy metals, dyes, and phenolic compounds, significantly release harmful pollutants into water bodies. Refinery wastewater treatment is essential to meeting the growing water demand and safeguarding downstream users from health hazards. Marine algae are one of the most popular adsorbents and biofilters for treating industrial effluent, and they have many advantages over other materials. These include being readily available in large quantities, having various functional groups (such as carboxyl, hydroxyl, sulfate, and phosphate), inexpensive, and being environmentally acceptable. In this research, green seaweed, "Ulva lactuca," was naturally found in the batch treatment of refinery wastewater in the most efficient, cost-effective, and environmentally friendly way, utilizing limited resources. The surface morphological characterizations of the seaweed before and after treatment are carried out using Scanning Electron Microscopy (SEM). A series of batch experimental studies were carried out to remove organics from refinery wastewater by varying the effluent solution pH, mixing time, stirring speed, algae dosage, and effluent solution temperature. The study mainly focused on determining parameters like Chemical Oxygen demand COD), Total Dissolved solids (TDS), Total Suspended solids (TSS), Turbidity, and Dissolved oxygen before and after treatment. The study demonstrates that the optimal efficiency of the treatment process occurs at a pH of 6, with 90 minutes of stirring time, a dosage of 0.8-1 g of Ulva lactuca, a stirring speed of 60-140 RPM, and a solution temperature of 35°C. The experimental results of the present study demonstrate that green seaweed, Ulva lactuca, is an eco-friendly and cost-effective biosorbent for effectively removing contaminants from refinery effluent. Ulva lactuca exhibited excellent pollution removal efficiency, significantly reducing chemical oxygen demand, dissolved oxygen, turbidity, dissolved solids, and suspended matter.

***Keywords**:* Algae, biosorption, Ulva lactuca, wastewater.

1. Introduction

The wastewater generated from refineries and petrochemical industries discharges considerable amounts of solid, liquid, and gaseous waste materials, which harm human and marine life [1]. The common pollutants from those industries are chemicals, organic and inorganic materials, herbicides, pesticides, pharmaceuticals, leather, textiles, plastics, pigments, electroplating, storage batteries, mining, smelting, metallurgical processes, etc. [2,3]. The petroleum industry produces large quantities of wastewater containing hydrocarbons, toxic substances, phenols, and heavy metals. The primary sources of petroleum industry wastewater are drilling fluids, various processing stages, cooling, and huge volumes of processed water discharge [4]. The petroleum industries' effluent is composed of oils, phenols, grease, sulfides, ammonia, and organic compounds and is very complex [5]. Conventional wastewater treatment techniques impose stringent pollutant limits that are obligatory before reprocessing the wastewater and discharging it into the environment. The significant drawbacks of standard wastewater treatment techniques are that they are highly energy-oriented, generate greenhouse gases into the environment, contain recyclable materials, and utilize unwarranted landfills [6,7].

2. Material and Method

2.1 Collection and characterization of wastewater

Some analyses, such as COD, TSS, Turbidity, TDS, and DO, were performed on industrial wastewater. The wastewater was diluted by adding 50 ml of industrial wastewater and 450 ml of distilled water to a 500 ml Erlenmeyer flask.

2.2 Collection and preparation of Ulva lactuca

The green algae *Ulva lactuca* was collected from the coast of Oman. The absorbent was washed with distilled water to remove the soluble materials (Minerals) and particulate matter. Then sun-dried for one day and dried in the oven for 4 hours at a temperature of 105°C. After that, the adsorbent was ground to reduce the particle size to less than 75 micrometers. Then HCl was added at a concentration of 1N and left for 4 hours. It was washed with distilled water and separated from the algae using a centrifuge. The adsorbent was dried at 60°C overnight

2.3 Adsorbent characteristics

Fourier Transform Infrared Spectroscopy (FTIR) was conducted on the samples of the green algae *Ulva lactuca* both before and after absorption, as well as after the stripping process, to compare the adsorbent characteristics. Additionally, Scanning Electron Microscopy (SEM) micrographs were obtained for the biosorbent algae before and after treatment to analyze the surface morphology changes.

2.4 Batch Treatment of Refinery Wastewater

A batch experimental study was performed using *Ulva lactuca* to remove organics from refinery wastewater by varying the processing parameters (effluent solution pH, contact time, algae dosage, stirring speed, and processing temperature).

2.5 Study the effect of pH

To study the influence of parameter reductions on the variation of effluent pH, the effluent solution pH changed from acidic to alkaline (from 2.0 to 12.0 pH). The parameter reductions were determined by measuring the COD, TDS, TSS, DO, and turbidity. The percentage reductions in parameters were determined.

2.6 Effect of Variation of Stirring Time

The effect of varying the stirring time was studied by varying the stirring time from 15 minutes to 120 minutes for the biosorbent *Ulva Lactuca.*

2.7 Effect of Variation of Stirring Speed

The influence of stirring speed on pollutant removal was studied by varying the stirring speed from 20 RPM to 180 RPM at optimized pH and stirring time.

2.8 Effect of Variation of Dosage of Biosorbent

The effect of dosage variation was investigated by changing the dosage of the adsorbent from 0.1 g to 1.0 g, and the parameter reductions were determined.

2.9 Effect of Variation of temperature

The temperature effect on percentage removal efficiency was studied by varying the effluent solution temperature from 25°C - 65°C by keeping all other conditions the same.

3. Results and Discussion

3.1 Characteristics of industrial wastewater

The characteristics of industrial wastewater were studied, and the values of COD (BOD)5, TSS, Turbidity, TDS, and DO were measured. The results shown in the table below were obtained.

Table I: Characteristics of Industrial Wastewater

Parameters	Values
COD, mg/L	1200
$(BOD)_5$, mg/L	309
TSS, mg/L	320
Turbidity, NTU	410
TDS, mg/L	212
DO, mg/L	3.40

3.2 Characterization of the biosorbent Ulva Lactuca

Biosorbents from *Ulva lactuca were* characterized using a Scanning Electron Microscope (SEM) and Fourier Transforms Infrared (FTIR). The SEM micrograph of the biosorbent algae for the *Ulva lactuca* was obtained, as shown in Figure 1. Figure 1(a) indicates the presence of macropores on the surface of the adsorbent before treatment for *Ulva lactuca*. Figure 1(b) represents the surface morphology of the adsorbent after treatment for *Ulva lactuca*. The adsorbent surface exhibits a thick layer, indicating successful organic pollutant adsorption on *Ulva lactuca*. The algae's surface morphology changed after the biosorption process, showing a tendency to form a thick microstructure.

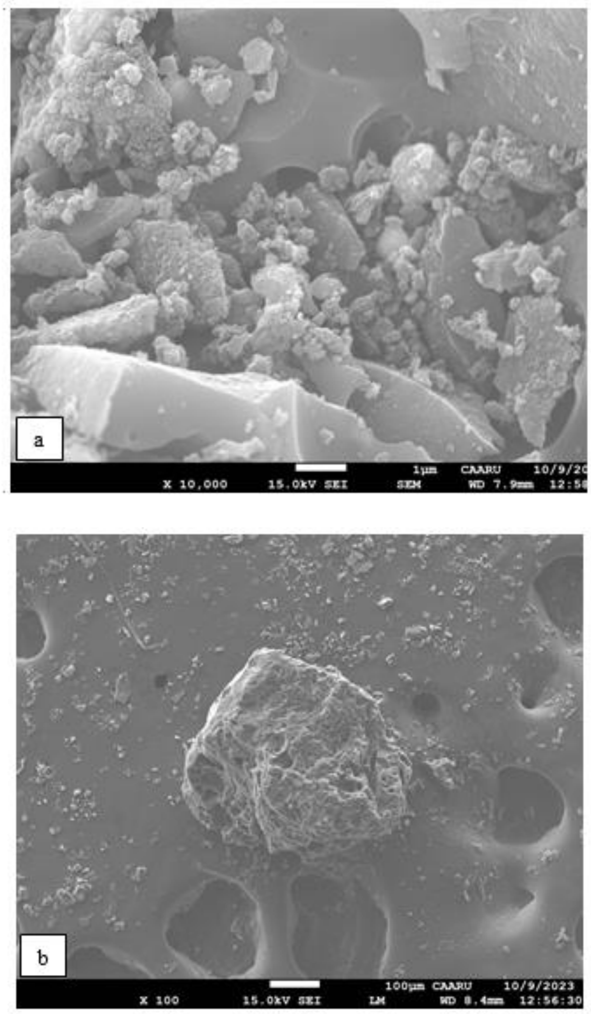

Figure 1. SEM micrographs of biosorbent algae (a) Ulva lactuca before treatment (b) Ulva lactuca after treatment.

FTIR was used to characterize biosorbents produced from *Ulva lactuca*, identifying the surface functional groups responsible for the sorption of organics. The characteristic peaks at different wave numbers indicate the functional groups present in the adsorbent before and after treatment. Figure 2 shows the FTIR spectra of *Ulva lactuca* before treatment and after the treatment (wavenumber: 977.58 cm^{-1}- 1028.77 cm^{-1}), this region is indicative of cyclohexane ring vibrations, which can suggest the presence of cyclic hydrocarbons or related structures in the *Ulva lactuca*. These vibrations before and after treatment may imply the stability or alteration of such cyclic structures during the treatment process. The peak at 1646.78 cm^{-1} corresponds to the stretching vibrations of alkenyl C=C bonds, characteristic of unsaturated compounds like alkenes. In *Ulva lactuca*, these bonds may be part of fatty acids or other unsaturated organic molecules.

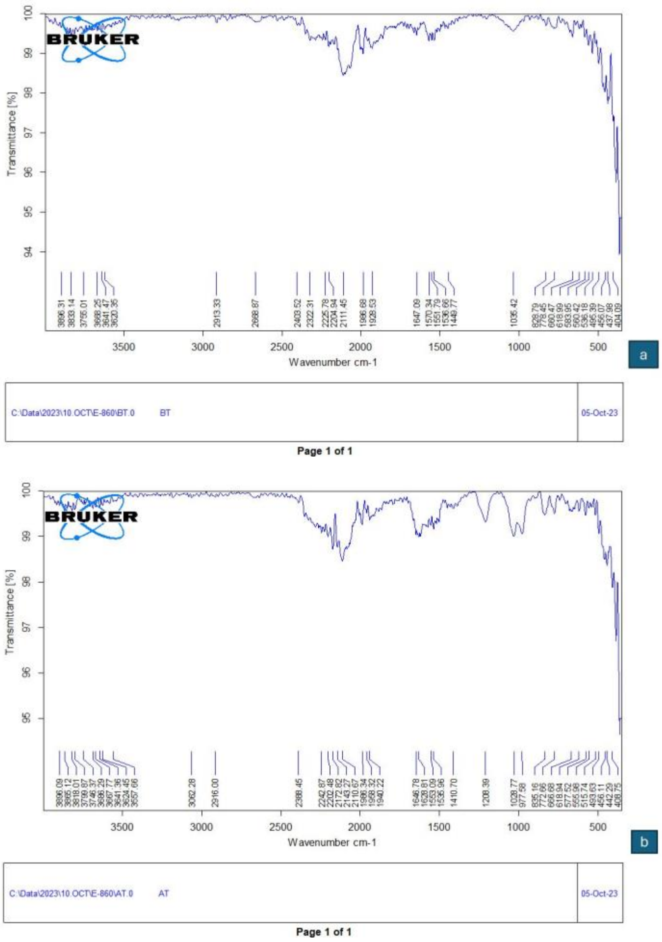

Figure 2. FTIR spectra of Ulva lactuca (a) before treatment (b) after treatment

3.3 The effect of pH

The effluent pH value varied from 2.0 to 12.0 to demonstrate the effect of pH on the biosorption of organics by *Ulva lactuc*a biomass. The results of this study are illustrated in Figure 3, which illustrates the relationship between solution pH and the percentage removal of effluent parameters COD, TSS, TDS, and Turbidity. The graph reveals that the removal efficiency of all measured parameters (COD, TSS, TDS, and Turbidity) initially increases with rising pH, reaches a peak, and then decreases. These findings indicate that the optimal pH for the biosorption of organics and other contaminants by *Ulva lactuca* biomass is around neutral (pH 6.0). The initial increase followed by a decrease in removal efficiency highlights the importance of maintaining the pH at an optimal level to ensure the effectiveness of the treatment.

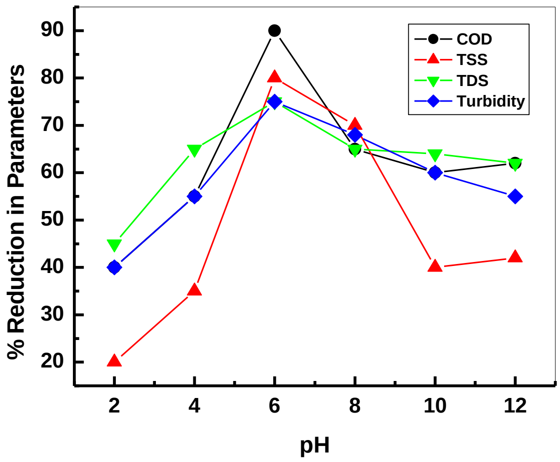

Figure 3. Effect of solution pH on % Removal Efficiency Using Ulva lactuca

3.4 The effect of contact time

The contact time varied from 15 minutes to 120 minutes. The results of this study are illustrated in Figure 4, which depicts the relationship between contact time and the percentage removal efficiency of key effluent parameters COD, TSS, TDS, and Turbidity. The graph shows a clear trend of increasing removal efficiency with longer contact times. From 15 minutes to 90 minutes, the removal percentages for COD, TSS, TDS, and Turbidity steadily increase. This indicates that extending the contact time allows the *Ulva lactuca* biomass to adsorb and remove contaminants from the effluent.

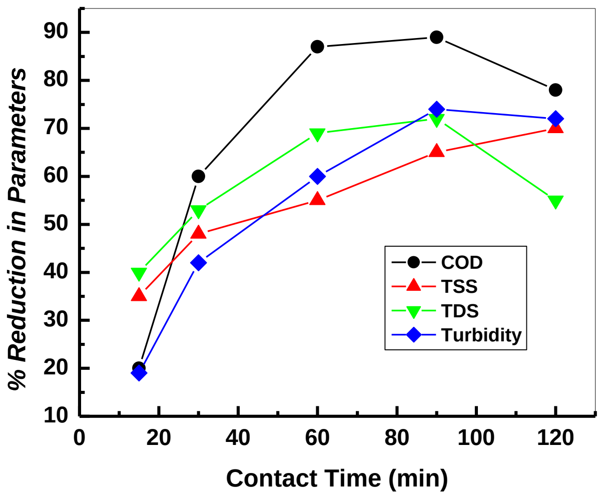

Figure 4. Effect of contact time on % Removal Efficiency Using Ulva lactuca

3.5 The effect of stirring speed

To investigate the impact of stirring speed on the biosorption of organics by *Ulva lactuca* biomass, the stirring speed varied from 20 rpm to 180 rpm. The results of this study are illustrated in Figure 5, which illustrates the relationship between stirring speed and the percentage removal efficiency of key effluent parameters COD, TSS, TDS, and Turbidity. As the stirring speed increases from 20 to 60 rpm, the removal efficiency for COD, TSS, TDS, and Turbidity also increases. The maximum removal efficiency for COD is achieved at 60 rpm, reaching 85%. The maximum removal efficiency for turbidity occurs at 100 rpm, reaching 78%. The highest removal efficiency for TSS is observed at 140 rpm, reaching 85%. The decrease in % removal beyond 140 rpm speed could be at a very high stirring speed, and the kinetic energy increased, which results in increased collision and, hence, the detachment of the loosely bound adsorbate molecules from the surface.

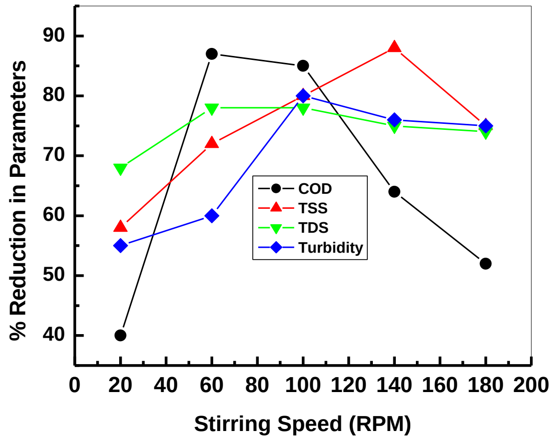

Figure 5. Effect stirring speed on % Removal Efficiency Using Ulva lactuca

3.6 The effect of adsorbent dose

To demonstrate the effect of biosorbent dosage on the biosorption of organics by *Ulva lactuca* biomass, the effluent dosage was varied from 0.1 g to 1.0 g. The results of this study are illustrated in Figure 6, which depicts the relationship between biosorbent dosage and the percentage removal efficiency of key effluent parameters: COD, TSS, TDS, and Turbidity. As the biosorbent dosage increases from 0.1 g to 1.0 g, the removal percentages for COD, TSS, TDS, and Turbidity also increase. This indicates that higher amounts of *Ulva lactuca* biomass provide more surface area and active adsorption sites, thereby enhancing contaminant removal. The maximum removal efficiency for COD is achieved at the highest dosage of 1.0 g, where it reaches 90%. This suggests that increasing the amount of biosorbent significantly improves the adsorption of organic compounds responsible for the chemical oxygen demand. The maximum removal efficiency for TSS, TDS, and Turbidity also improves with increased dosage, reaching up to 68%. This indicates a similar positive effect of higher biosorbent dosages on removing suspended solids, dissolved solids, and particulate matter. These findings indicate that higher dosages of *Ulva lactuca* biomass can significantly enhance the treatment efficiency by increasing the removal of various contaminants from refinery effluent.

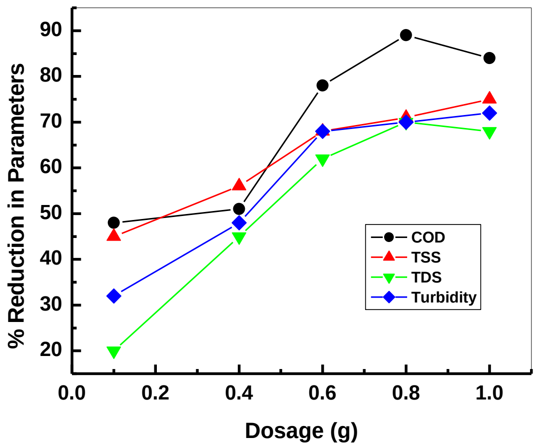

Figure 6. Effect of biosorbent dosage on % Removal Efficiency Using Ulva lactuca

3.7 The Effect of Variation of Temperature

To demonstrate the effect of temperature variation on the biosorption of organics by *Ulva lactuca* biomass, the temperature was varied from 25°C to 65°C. The results of this study are illustrated in Figure 7, which depicts the relationship between temperature and the percentage removal efficiency of key effluent parameters: COD, TSS, TDS, and Turbidity. These findings indicate that temperature is crucial in optimizing the biosorption process using *Ulva lactuca* biomass. The optimal temperature for maximum removal efficiency of COD, TSS, TDS, and Turbidity is 35°C.

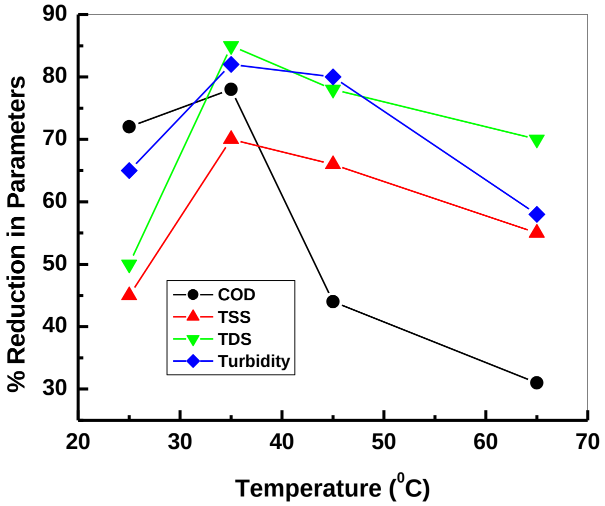

Figure 7. Effect of temperature on % Removal Efficiency Using Ulva Lactuca

4. Conclusion

To maintain a clean environment, wastewater must be purified, as it harms the environment and humans. Traditional methods for removing organic matter from wastewater often involve high costs, time, and effort. Consequently, there is a growing global shift toward finding more efficient, cost-effective, and less labor-intensive alternatives. This paper explores using the green algae *Ulva lactuca* to remove organic compounds from industrial wastewater. This paper discusses the effectiveness of *Ulva lactuca* in eliminating organic matter and minerals from wastewater. The study investigates the impact of various factors, including pH, contact time, temperature, stirring speed, and adsorbent dose, on the removal efficiency of organic compounds. Biosorbents derived from *Ulva lactuca* were analyzed using Scanning Electron Microscopy (SEM) and Fourier Transform Infrared (FTIR) spectroscopy. The experimental results revealed that *Ulva Lactuca* is highly effective in reducing chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), and turbidity. The optimal conditions identified were a pH of 6.0, a contact time of 90 minutes, a biosorbent dosage of 0.8 g, a stirring speed of 100 to 140 rpm, and a solution temperature of 35°C.

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