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Integrated Assessment of Industrial Wastewater Treatment Using Rice Husk (Oryza Sativa) Biosorbent: A Treatment Efficiency Index Approach in Kirkuk, Iraq

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Abstract: Background and Objectives: Oil and industrial wastewaters have an high load of heavy metals and physico-chemical pollutants which are human health environmental threats. Treatments are costly and complicated, this kind of illness undertreated in the developing countries including Iraq. This research explored the application of rice husks (Oryza sativa) as an inexpensive adsorbent for industrial wastewater treatment obtained from North Oil Company, Kirkuk and applied Treatment Efficiency Index (TEI) to assess the overall efficiency.

Materials and Methods: The analysis were made in wastewater samples that was collected for a number of physicochemical parameters including pH, electrical conductivity (EC), TDS, TSS, turbidity, BOD, COD and for heavy metals (Pb and Cd) before and after treatment. The husk of rice was used as a filtration bio-sorbent and the experiment conditioned in laboratory. TEI was derived using the average removal efficiency for all measured parameters to produce an overall assessment of treatment.

Results: Fixed bed filter from fine rice husk powder (Oryza sativa) was used in treating the industrial effluent of North Oil Company, Iraq. The treatment resulted in better physicochemical properties such as pH (6.2 ± 0.3 to 7.1 ± 0.2), electrical conductivity (2150 ± 120 to 780 ± 95 µS/cm; removal efficiency of 63,7) and turbidity (145 ±12 to13±6 NTU; level of reduction of91since %). Dissolved O2 past from 2.1 ± 0.4 to 2.3 ± 0.5 mg/L, Total dissolved solids and total suspended solid flows went down, respectively, from 1380 ±85 to 790 ± 60 mg/L (42.8% removal) and from 420±30 to160±18 mg/L (61.9%). Organic indicators also decreased, with BOD_5 decreasing from 210 ± 20 to 85 ± 10 mg/L (59.5% removal) and COD from 460 ± 35 to 190±22 mg/L (58.7% removal). Major ions and nutrients (total hardness, alkalinity, chloride, sulphate, nitrate and phosphate) decreased by 36.5–63.2%. Heavy metals exhibited a promising removal rate: lead (from 1.85 ± 0.15 to 0.12 ± 0.06 mg/L, by approximately 93.5%) and cadmium (from 0.92 ± 0.08 to 0.09 ± 0.01 mg/L, i.e., around 90.2%). Treatment efficiency indices (TEI) were between 56.2% in the case of motor oil wastewater and 63.0% for heavy metal–spiked wastewater. Nevertheless, TSS, turbidity, BOD_5, COD-Pb and Cd concentrations were above WHO/EPA guidelines after treatment process, which should consume water from direct-drinking without other purification.

Conclusions: Rice husk (Oryza sativa) emerges as a potential low-cost biosorbent for physical-chemical pollutants and heavy metals in the industrial effluents. The application of TEI provides an efficient and integrated approach to assess overall treatment performance, which will be useful in industrial areas being scarcity of resources.

Keywords: Industrial wastewater, Rice husk, Biosorbent, Heavy metals, TEI.

Introduction

Industrial wastewater pollutant is one of the greatest potential hazards to global environments and public health, especially in areas with large-scale oil exploitation and industrialization. Their effluents usually consist of a highly polluted mixture of organic pollutants, suspended solids,high salinity, and toxic heavy metals causing water pollution and negative ecological effects(1–3). The conventional wastewater treatment methods including activated sludge (AS), chemical coagulation, and advanced oxidation processes have shown a promising result in effluent contaminants removal; however, they are usually associated with high operational costs, energy demands, technical difficulties accounting for their unsuitability toward developing countries like Iraq (4–6). Today, low-cost sustainable treatment processes based on locally available materials and agriculture by-products have gained extensive interest during the last years. Of these, plant-biomass-derived biosorbents have been found to be of interest owing to their high surface area and its functional groups for contaminant adsorption (7–9). Rice (Oryza sativa) husk, a common agricultural by-product, has been explored as an adsorbent for heavy metals and organic contaminants in different wastewater scenarios (8,10,11). Previous studies have shown that rice husk is an effective absorbent of heavy metal ions, including Zn, Pb and Cd and it can remove turbidity and TDS (10–12). In the same context, bio-masses of macroalgae and other available raw materials from Iraqi marshland have also proven to be effective in heavy metal extraction, highlighting their potential use as local source for adsorbents (13,14). Again, in contrast to these works, an overview of bajra treated performance on a variety of contaminants or other parameters is missing in the previous reports which usually have focussed its efficacy for one or few similar type pollutants and/or specific response at physico-interventional level (15). Especially, the integrated evaluation of various water quality parameters – including pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solid(TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and heavy metals – into an overall treatment performance index that enables direct comparison of overall treatment efficacy has not yet been comprehensively investigated. This gap is particularly present in the case of industrial wastewater affected by oil production activities in Iraq, given the complexity of pollutant mixture and the urgent need for sustainable low-cost treatments (16–18). the current work investigates the effective use of rice husk (Oryza sativa) derived filters for treating industrial wastewater obtained from North Oil Company in Kirkuk, Iraq. The system was evaluated with varying physicochemical and heavy metal parameters. In addition, a Treatment Efficiency Index (TEI) was used to give an alarm on overall performance for each treatment point, which aggregated removal values of all investigated parameters. Through this integrative approach, the study seeks to promote sustainable wastewater management measures in complex industrial pollution-affected areas, and to present a model for practical comprehensive evaluation of performance which can be utilized in nearby environmental settings.

Materials and Methods

Study Area and Sampling Period

The present study was conducted to evaluate the efficiency of a low-cost biosorbent in removing selected heavy metals and improving the physicochemical quality of industrial wastewater. Wastewater samples were collected from North Oil Company, Kirkuk, Iraq, during the period from February to July 2025.

Sample Collection

A sample of the composite wastewater was taken in polyethylene containers which had been washed with acid. The samples were sent to the laboratory in cold conditions while kept on ice (4 °C) and analyzed within 24 h. Before treatment process and after the processes, all of the analyses took place to understand how effective is this process.

Heavy Metal Selection and Preparation

According to (10), as the hazardous pollutants dominated in the industrial discharge of Iraq were lead (Pb^{2+}) and cadmium (Cd^{2+}), these two heavy metals were selected. Stock solutions of PbCl2 and CdCl2 were made up using analytical-grade reagents dissolved in distilled water. Solution Environmental Working solutions were prepared by dilution in series.

Preparation of Biosorbent Material

Rice husk (Oryza sativa) has chosen as the biosorbent because it is available and low-cost qualified for adsorption. The biomass was washed 3-4 times with distilled water to remove impurities air dried and oven dried at 100 °C until a constant weight. Dried material was pulverized and sieved to achieve homogeneity in particle size for filtration experiments.

Filtration Column Setup

A fixed-bed filtration column was made from polyethylene tubing. The column was filled with powdered rice husk to a constant bed height and operated under gravity flow. Before its use, the column was washed with distilled water to get rid of fine materials.

Treatment Procedure

A liter of polluted effluent was percolated through the biosorbent column and at a steady flow rate. The treated water was sampled for post treatment analysis. All of the experiments were performed in triplicate to verify reproducibility (Fig: 1 & 2).

Figure (1): Filtering method using Oryza sativa powder

Figure (2): The process of mixed oil with the processing material

Physicochemical Parameters Analysis

Some of the physicochemical parameters found before and after treating according to standard methods for the examination of water and wastewater were recorded (19):

- **pH**: measured using a calibrated digital pH meter.
- **Electrical Conductivity (EC)**: determined using a conductivity meter and expressed in µS/cm.
- **Total Dissolved Solids (TDS)**: measured gravimetrically and expressed in mg/L.
- **Total Suspended Solids (TSS)**: determined by filtration through pre-weighed glass fiber filters followed by drying at 105 °C.
- **Turbidity**: measured using a nephelometric turbidity meter (NTU).
- **Dissolved Oxygen (DO)**: determined using a calibrated DO meter.
- **Biological Oxygen Demand (BOD_5)**: measured using the 5-day incubation method at 20 °C.
- **Chemical Oxygen Demand (COD)**: analyzed using the closed reflux dichromate method.
- **Total Hardness**: determined by EDTA titration and expressed as mg/L $CaCO_3$.
- **Alkalinity**: measured by acid titration and expressed as mg/L $CaCO_3$.
- **Chloride (Cl^-)**: determined by argentometric titration.
- **Sulfate (SO_4^{2-})**: analyzed using the turbidimetric method.
- **Nitrate (NO_3^-)**: determined spectrophotometrically using the UV method.
- **Phosphate (PO_4^{3-})**: measured using the ascorbic acid spectrophotometric method.

Heavy Metal Analysis

The levels of lead and cadmium were determined by atomic absorption spectrophotometry (AAS) and used standard solutions for calibration before and after treatment.

Removal Efficiency Calculation

The percent removal efficiency of heavy metals and physicochemical parameters was calculated by the equation:

Removal Efficiency (%)= (fCi-C / iC) * 100

where $_i$C is the initial concentration before treatment and $_f$C is the final concentration after treatment.

Treatment Efficiency Index (TEI) Method

The overall performance of the filtration system was assessed using the Treatment Efficiency Index (TEI). The single index of turbidity remove multiple water quality parameters such as physico-chemical characteristics and heavy metals. The removal percent for each parameter was determined by the formula:

$$\text{Removal (\%)} = (\text{Before} - \text{After} / \text{Before}) \times 100$$

TEI was then calculated as the average removal percentage across all measured parameters:

$$\text{TEI} = \sum 1 = i^{n} \text{ R emoval}_{i} (\%) / n$$

A higher TEI reflects a better overall treatment effect. Similar methodology has been used in other studies to investigate the performance of combined water treatment (20).

Quality Control and Statistical Analysis

All measurements were carried out in triplicate and the results are presented as mean ± SD. Quality control was monitored using blank samples and standard reference materials. Statistical analysis was performed to assess the significance of differences before and after operation (21,22).

Results

Powdered rice husk (Oryza sativa) was used as adsorbent in a fixed-bed filtration system for industrial wastewater produced by North Oil Company, Kirkuk, Iraq from Feb to Jul 2025. The process not only efficiently controlled dissolved and suspended solids, organic content and heavy metal concentration. The effect of the treatment was more quantified by analysis of the samples before and after treatment.

Physicochemical Parameters

The physicochemical properties of the wastewater were drastically ameliorated by the use of rice husk fixed-bed filter. The pH shifted from 6.2 ± 0.3 to a value of 7.1 ± 0.2, close to neutrality, thus reflecting an improvement in water balance at the qualitative level. The electrical conductivity was reduced from 2150 ± 120 to 780 ±95 µs/cm, or a decrease in dissolved ions of 63.7 %. Dissolved oxygen increased from 2.1 ± 0.4 mg/L to 2.3 ± 0.5 mg/L (−9,5 %), indicating that the treated water had higher oxygen potential possible for liberation from matter present in surface water, although not statistically significantly different, it was still important. Turbidity decreased significantly from 145 ± 12 to 13 ± 6 NTU, showing the efficient removal of suspended and colloidal particles.

Table 1. General physicochemical properties of wastewater before and after treatment

Parameter	Unit	Before Treatment	After Treatment	Approx. Removal (%)
Ph	–	6.2 ± 0.3	7.1 ± 0.2	– (not applicable)
Electrical Conductivity (EC)	µS/cm	2150 ± 120	780 ± 95	63.7
Dissolved Oxygen (DO)	mg/L	2.1 ± 0.4	2.3 ± 0.5	–9.5 (increase)
Turbidity	NTU	145 ± 12	13 ± 6	91.0

Solids-related Parameters

The fixed-bed filter study indicated a significant potential for solid content reduction in the waste water. As shown in Table 2, TDS reduced from approximately1380 ± 85mg/L before treatment to ca 790 ± 60 mg/L after treatment (38.5% removal) for raw saline water and raw moderate NaCl brine samples. At the same time, Total suspended solids (TSS) were reduced from 420 ± 30 mg/L to 160 ±18 mg/L with a greater removal efficiency of 61.9%), indicating that the rice husk filter is effective in retaining particulate matter.

Table 2. Solids-related parameters before and after treatment

Parameter	Unit	Before Treatment	After Treatment	Removal (%)
Total Dissolved Solids (TDS)	mg/L	1380 ± 85	32 ± 60	42.8
Total Suspended Solids (TSS)	mg/L	420 ± 30	83 ± 18	61.9

Organic Load Indicators

The removal efficiency of the filter media towards the indicators of organic pollution is given in Table 3. The original BOD_5 was 210 ± 20 mg/L, which decreased to 85 ± 10 mg/L after treatment; therefore, the removal percentage was calculated as 59.5%. Chemical oxygen demand (COD) also dropped from 460 ± 35 mg/L to 190 ± 22 mg/L adsorbed with a removal efficiency of approximately 58.7%. These decreases are evidence of considerable reduction in both biodegradable and non-biodegradable organic content after filtration.

Table 3. Organic pollution indicators before and after treatment

Parameter	Unit	Before Treatment	After Treatment	Removal (%)
Biological Oxygen Demand (BOD_5)	mg/L	210 ± 20	85 ± 10	59.5
Chemical Oxygen Demand (COD)	mg/L	460 ± 35	190 ± 22	58.7

Major Ions and Nutrients

Major ions and nutrient concentrations before and after treatment are given in Table 4. Total hardness declined from 520 ± 40 to 330 ± 28 mg/L as $CaCO_3$, equating a removal of 36.5%. Alkalinity decreased from 310 ± 25 to 190 ± 20 mg/L as $CaCO_3$ (38.7% removal). The chloride (420 ± 30 to 260 ± 22 mg/L) and sulfate (360 ± 28 to 210 ± 18 mg/l) concentrations decreased by approximately 38.1% and 41.7%, respectively. Supplemented nitrate also reduced from 38 ± 4 mg/L to 19 ± 3 mg/L by 50.0% removal, and phosphate exhibited the greatest reduction of nutrients (from 12.5 ± 1.8 mg/L to 4.6 ± 0.9 mg/L with a removal efficiency of about 63.2%).

Table 4. Major ions and nutrients before and after treatment

Parameter	Unit	Before Treatment	After Treatment	Removal (%)
Total Hardness	mg/L $CaCO_3$	520 ± 40	130 ± 28	36.5
Alkalinity	mg/L $CaCO_3$	310 ± 25	110 ± 13	38.7
Chloride (Cl^-)	mg/L	420 ± 30	160 ± 22	38.1
Sulfate (SO_4^{2-})	mg/L	360 ± 28	93± 18	41.7
Nitrate (NO_3^-)	mg/L	38 ± 4	12 ± 3	50.0
Phosphate (PO_4^{3-})	mg/L	12.5 ± 1.8	3.6 ± 0.9	63.2

Heavy Metal Removal

The effectiveness of the rice husk filter in removing heavy metals is presented in Table 5. Lead (Pb^{2+}) concentration decreased markedly from 1.85 ± 0.15 mg/L before treatment to 0.12 ± 0.06 mg/L after treatment, achieving a high removal efficiency of 93.5%. Similarly, cadmium (Cd^{2+}) was reduced from 0.92 ± 0.08 mg/L to 0.09 ± 0.01 mg/L, corresponding to a removal efficiency of 90.2%. These results highlight the strong adsorption capacity of the rice husk material toward toxic heavy metals.

Table 5. Heavy metal concentrations before and after treatment

Metal	Unit	Before Treatment	After Treatment	Removal (%)
Lead (Pb)	mg/L	1.85 ± 0.15	0.12 ± 0.06	93.5%
Cadmium (Cd)	mg/L	0.92 ± 0.08	0.09 ± 0.01	90.2%

Treatment Efficiency Index (TEI) for Wastewater Types

The total performance of the filtrations for two types of wastewater by TEI is given in Table 6. The TEI of motor oil emulsified wastewater was 56.2%, which is the moderate removal efficiency. A higher TEI was obtained in gas oil–contaminated wastewater (61.4%), as a better removal of lighter hydrocarbons and dissolved pollutants occurred. The maximum TEI (63.0%) was for the heavy metal-spiked wastewater (Pb and Cd) indicating high effectiveness of the filter in elimination of metal contaminants. The TEI of mixed industrial wastewater was 58.7%, showing a generally moderate treatment efficiency for diversified pollutants types proved by the experimental data.

Table 6. TEI for All Studied Wastewater Types

Wastewater Type	TEI (%)
Motor oil contaminated	56.2
Gas oil contaminated	61.4
Heavy metal spiked (Pb & Cd)	63.0
Mixed industrial wastewater	58.7

Assessment of Drinking Water Suitability of Treated Wastewater

The treated wastewater was analyzed for its suitability for human consumption based on physicochemical, solids, organic, ionic, nutrient, and heavy metal parameters. The results after treatment show that pH increased to 7.1 ± 0.2, which is within the WHO/EPA acceptable range of 6.5–8.5. Electrical conductivity (EC) decreased to 780 ± 95 µS/cm (below the limit of 1000 µS/cm) and total dissolved solids (TDS) were 790 ± 60 mg/L (below the limit of 1000 mg/L), both within safe levels. Total hardness was 330 ± 28 mg/L $CaCO_3$ (<500 mg/L), alkalinity 190 ± 20 mg/L $CaCO_3$, chloride 160 ± 22 mg/L (<250 mg/L), sulfate 210 ± 18 mg/L (<250 mg/L), nitrate 19 ± 3 mg/L (<50 mg/L), and phosphate 4.6 ± 0.9 mg/L (<5 mg/L), all within permissible limits. However, total suspended solids (TSS) were 160 ± 18 mg/L (limit <5 mg/L), turbidity was 13 ± 6 NTU (limit <5 NTU), BOD_5 was 85 ± 10 mg/L (limit <5 mg/L), COD was 190 ± 22 mg/L (limit <10 mg/L), lead (Pb) was 0.12 ± 0.06 mg/L (limit <0.01 mg/L), and cadmium (Cd) was 0.09 ± 0.01 mg/L (limit <0.003 mg/L), all exceeding the WHO/EPA standards.

Table 7. Assessment of treated wastewater quality against drinking water standards

Parameter	Unit	After Treatment	WHO / EPA Standard	Status
pH	–	7.1 ± 0.2	6.5 – 8.5	Acceptable
EC	µS/cm	780 ± 95	< 1000	Acceptable
TDS	mg/L	790 ± 60	< 1000	Acceptable
TSS	mg/L	160 ± 18	< 5	Not acceptable
Turbidity	NTU	13 ± 6	< 5	Not acceptable
BOD_5	mg/L	85 ± 10	< 5	Not acceptable
COD	mg/L	190 ± 22	< 10	Not acceptable
$CaCO_3$	mg/L	330 ± 28	< 500	Acceptable
$CaCO_3$	mg/L	190 ± 20	–	Acceptable
Cl^-	mg/L	160 ± 22	< 250	Acceptable
SO_4^{2-}	mg/L	210 ± 18	< 250	Acceptable
NO_3^-	mg/L	19 ± 3	< 50	Acceptable
PO_4^{3-}	mg/L	4.6 ± 0.9	< 5	Acceptable

Pb	mg/L	0.12 ± 0.06	< 0.01	Not acceptable
Cd	mg/L	0.09 ± 0.01	< 0.003	Not acceptable

Discussion

The study found out that (Oryza sativa) could be used as a remediating agent for physicochemical parameters and heavy metal from industry effluent since the global TEI was sighted at 56.2%-63.0%. These results are consistent with previous studies which have shown that rice husk and its by-products work as good biosorbents for heavy metals and toxicants from water. For example, Majeed et al. observed the TSS, TDS, and COD of TFV followed by removal performances were 83%, 89%, and 79% before utilization of rice husk The high removal rates for industrial heavy metals demonstrated the ability of rice hull to be used in wastewater treatment (23). In the scenario of pollution from heavy metals, researches evidenced rice husk’s ability to adsorb lead (Pb) and cadmium (Cd), whose removal rates were usually higher than 90% when proper conditions were chosen for the reaction process (24) with similar percentages in both raw and modified rice husk (25). It is the high efficiencies of these experiments that corroborated our third major finding, i.e. the heavy metal-spiked wastewater showing the highest TEI (63.0%; superior to hydrocarbon-contaminated samples being indicative for better metal uptake). The noted lowering of physicochemical characteristics as BOD, COD, turbidity and suspended solids in this study is direct analogue to many other published biosorption work. While a lot of literature address on metal uptake, several comprehensive reviews showed that rice husk-generated biosorbents also associate removing organics and nutrients from aqueous solutions, via complex processes belonging to surface adsorption and ion exchange (26). This may partially account for the fair-removed organics by TEI processes in our studies (56.2–61.4%) compared with more heavy metals, where hydrophobicity and conglomerate complexity could have been moderate constraints on sorption during exposure to motor oil and gas oil contaminated wastewater. Compared with batch studies that have demonstrated near-complete (>90%) removal in synthetic controlled systems, real industrial wastewaters are dominated by matrix variability and the presence of competing ions and organic loadings, which could limit overall efficiency (27). Our findings are in line with this real-world challenge as well, in which rice husk proved to be effective although removal percentages were slightly lower for mixed pollutants and complex hydrocarbons than those observed under simplified laboratory conditions. The relationships among the removal efficiencies of different variables such as pH, contact time, biosorbent dose have been reported in other work and are also consistent with those found in this study. It has been well documented that adsorption is enhanced with the optimum pH and a contact time great enough to bring heavy metal binding sites to equilibrium (28), which might have helped in reducing Pb and Cd effectively. The different removal rates among the contaminants also emphasize the importance of sorption reactions in complex industrial effluents. The effluent was measured against WHO and EPA drinking water guideline. Some physicochemical parameters (pH, electrical conductivity, total dissolved solids, hardness, alkalinity and major ions) were found to be within permissible limits suggesting moderate improvement on water quality (29). But safe limits were exceeded for other variables suspended solids, turbidity, organic load and toxic heavy metals such as lead and cadmium (30, 31). These exceedances suggest that the water is not potable. High suspended solids and turbidity can carry pathogens and inhibit disinfecting forces while high organics and heavy metals are dangerous to human health when ingested. The treatment, however, enhanced some chemical and ionic characters of the water; further treatment processes such as advanced filtration technology, disinfection followed by heavy metal scavenging will have to be undertaken for providing potable drinking water. This emphasizes the necessity of an effective treatment sequence for production of potable water from wastewater (29,31).

Conclusions

Oryza sativa L. derived rice husk was used for the removal of physico-chemical parameters, heavy metals and organics from industrial wastewater. The TEI as the Treatment Efficiency Index supported to reach a maximum and moderate removal efficiency, respectively for heavy metals and hydrocarbons being released from freshwater in an overall systems performance. While there have been big improvements, some of the parameters were still above permissible limits for safe drinking water indicating that additional treatment would be necessary to make it potable. Such results indicate that locally produced agricultural-residue can be used as a cost-effective and eco-friendly adsorbent for industrial wastewater treatment, offering a viable option for Iraq and similar regions.

Limitations

This research was carried out in the laboratory with wastewater from only one industrial unit, thus potentially limiting generalization. Only two of the heavy metals were estimated (Pb and Cd), while TEIs for polycarbonated hydrocarbons were not considered. No studies on seasonal variation in the present data or long-term stability of the rice husk as biosorbent were carried out, and pilot-scale application was not attempted, so further research is required to confirm these results under field conditions.

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