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Experimental Studies on Removal of Organic Pollutants from Textile Industrial Wastewater using Orange Peel

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Abstract: Effluents discharged from textile manufacturing units carry substantial loads of organic and inorganic contaminants, including synthetic dyes, phosphates, fluorides, nitrates, sulfates, chlorides, elevated Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), along with high turbidity. Managing such effluents remains a significant challenge for small and medium-scale industries, primarily owing to financial constraints, operational complexity, and the generation of secondary waste. The present study investigates the potential of orange peel powder, a widely available agricultural by-product, as an adsorbent for treating textile mill effluents. Powdered orange peel was prepared and subjected to batch adsorption trials across a dosage range of 2–10 g/L and contact durations of 0–90 min. Orange peel was found effective in reducing pollutants like turbidity, fluoride, chloride, Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). Maximum adsorption was observed at 10 g/L dosage and 90 min contact time. The optimal dosage was found between 8 and 10 g/L. This study reveals that orange peel can be an alternative adsorbent material in adsorbing these pollutants from textile industry wastewater, making it an eco-friendly, cost-effective, and sustainable method.
Keywords: Textile wastewater, Orange peel, Adsorption, Organic pollutants, Low-cost adsorbent, Eco-friendly treatment, Batch study.

1. Introduction

Textile manufacturing ranks among the most water-consuming industrial sectors globally, releasing large volumes of effluent laden with hazardous constituents. Such effluents typically carry synthetic dyes, phosphates, fluorides, nitrates, sulfates, and chlorides, and exhibit elevated levels of COD, BOD, and turbidity. The presence of these contaminants in the wastewater poses serious threats to the aquatic environment and living organisms [13].The conventional wastewater treatment techniques employed so far include coagulation-flocculation, activated sludge processing, membrane filtration, and chemical precipitation. However, these techniques are costly and energy-intensive and also produce secondary sludge that needs to be treated and disposed of. Therefore, they are economically nonviable for small and medium-scale industries, especially in developing countries like India that have thousands of textile industries without adequate wastewater treatment facilities [8].

In recent times, the use of the adsorption technique using low-cost and naturally occurring materials has been proposed as an economically viable and sustainable option for the treatment of wastewater. Agro-industrial residues such as rice husk, coconut shell, banana peel, and citrus peels have demonstrated considerable potential in sequestering contaminants from water bodies, owing to their porous morphology and the abundance of hydroxyl and carboxyl surface groups [4-5]. Orange peel is a readily available agricultural waste material that is abundantly produced during food processing and juice industry activities. Orange peel is composed of cellulose, pectin, and hemicellulose. These are active sites for adsorption and ion exchange. Orange peel has been scientifically proven to be effective in removing various metallic ions [11], dyes [7, 14], and organic chemicals [8] from aqueous solutions. However, detailed research on its application for removing various parameters such as turbidity, fluoride, chloride, BOD, and COD from textile industrial wastewater is still in its infancy.This work presents laboratory-scale investigations into the deployment of orange peel powder as a low-cost adsorbent for textile effluent remediation. Pollutant removal performance was assessed across varying adsorbent doses and equilibration periods, contributing to the growing literature on waste-derived materials for sustainable water treatment [9-10].

2. Literature Survey

Orange peel has been found to be a cost-effective adsorbent for wastewater treatment. Channa et al. (2025) demonstrated the effective remediation of hexavalent chromium from industrial effluents using orange peel as a biosorbent, confirming its potential as a low-cost alternative to conventional treatment methods [1]. For removing dyes from wastewater, Priyanka et al. (2021) were able to remove 91.2% methylene blue from wastewater at pH 6 and 120 minutes contact time. A positive correlation was observed between adsorbent dose and pollutant removal efficiency [3, 12]. Sriramula et al. (2023) evaluated the efficiency of orange and banana peels for dye removal from synthetic industrial effluent and confirmed significant pollutant reduction [4]. The adsorption behaviour of orange peel has been characterised using equilibrium isotherm models. Mashi et al. (2024) determined a peak adsorption capacity of 17.69 mg/g for methyl orange dye, with the Langmuir isotherm yielding an R^2 value of 0.9964, indicating monolayer adsorption dominance [7]. Beni and Esmaeili (2023) examined a broad range of agro-waste derived adsorbents, evaluating their performance against toxic pollutants in water and discussing the underlying equilibrium and kinetic frameworks [9]. Raksha and Asha Rani (2021) demonstrated that orange peel, when applied as a natural coagulant, achieved notable reductions in turbidity and suspended solids in wastewater [2].

Collectively, these studies have verified the use of orange peel as a viable and effective adsorbent material in various wastewater treatment applications.

3. Materials and Methods

3.1 Collection and Characterization of Wastewater Sample

The textile wastewater sample was collected from a local textile dyeing industry in Coimbatore, Tamil Nadu, India. The sample was stored in clean plastic containers and kept at 4°C before analysis. Initial characterization was conducted in order to identify the initial values of pH, turbidity (measured in Nephelometric Turbidity Units (NTU)), fluoride, chloride, BOD, and COD. The initial values of these parameters in wastewater are shown in Table 1.

Table 1: Initial Wastewater Characteristics

PARAMETER	VALUE	PERMISSIBLE LIMIT (Central Pollution Control Board (CPCB)/IS 2490)	REMARKS
Chlorides	800 mg/L	200 mg/L	High due to dyeing and bleaching salts
Fluorides	2.00 mg/L	2 mg/L	Present from bleaching chemicals
pH	8.39	5.5–9	Alkaline in nature
Turbidity	150 NTU	—	Due to suspended dyes and fibers
BOD	350 mg/L	30 mg/L	Indicates high organic pollution
COD	900 mg/L	250 mg/L	Shows high chemical contamination

3.2 Preparation of Orange Peel Adsorbent

Orange peels sourced from a nearby fruit juice outlet served as the raw adsorbent material. Prior to processing, the peels underwent multiple rinses with distilled water to eliminate surface impurities. Solar drying was initially employed to reduce moisture content, followed by forced-air oven drying at 80°C for 2 hours to achieve full desiccation. The desiccated material was subsequently ground in a mechanical mill and passed through a 150 µm mesh screen to obtain a uniform powder.

3.3 Experimental Procedure – Batch Adsorption Study

Batch equilibrium experiments were performed in 1000 mL glass beakers. Orange peel powder was introduced at five concentration levels of 2, 4, 6, 8, and 10 g/L into 500 mL aliquots of the textile effluent. Continuous agitation was maintained throughout each run using a magnetic stirrer operating at a fixed rotational speed. Aliquots were withdrawn at predetermined intervals of 0, 15, 30, 45, 60, and 90 minutes, clarified by passage through Whatman No. 1 filter paper, and subsequently analysed for pH, turbidity, Fluoride, Chloride, BOD, and COD.

3.4 Analytical Methods

The following standard analytical methods were used for parameter determination:

Phosphate (PO_4^{3-}): Stannous Chloride ($SnCl_2$) / Ascorbic Acid Method – Absorbance measured at 690 nm.

Fluorides (F^-): Sulfophenyl Azo Dihydroxy Naphthalene Disulfonic Acid (SPADNS) Colorimetric Method – Absorbance measured at 570 nm.

Nitrates (NO_3^-): Phenoldisulphonic Acid Method – Absorbance measured at 410 nm.

Sulphate (SO_4^{2-}): Turbidimetric Method – Absorbance measured at 420 nm.

Chlorides (Cl^-): Argentometric (Mohr's) Titration – Titrated with 0.0141 N Silver Nitrate ($AgNO_3$).

COD: Dichromate Reflux Method – Digested with Potassium Dichromate ($K_2Cr_2O_7$) and Sulphuric Acid (H_2SO_4).

BOD_5: 5-day Incubation Method – Measured as difference in dissolved oxygen at 20°C.

Turbidity: Nephelometric Method – Measured in NTU using nephelometer.

4. Results and Discussion

4.1 Effect of Dosage and Contact Time on Pollutant Removal

The experimental results for different dosages of orange peel powder, ranging from 2 to 10 g/L, at contact times ranging from 0 to 90 minutes are presented in Tables 2, 3, 4, and 5. In Table 6, the percent removal of individual parameters at a contact time of 90 minutes for different dosages is presented.

Table 2: Results at 2 G/L Orange Peel Dosage

Time (min)	pH	Turbidity (NTU)	Fluoride (mg/L)	Chloride (mg/L)	Biochemical Oxygen Demand (mg/L)	Chemical Oxygen Demand (mg/L)
0	8.39	150	2.00	800	350	900
15	8.15	140	1.90	780	330	870
30	7.95	130	1.80	760	310	830
45	7.80	120	1.75	745	295	800
60	7.70	115	1.72	735	285	790
90	7.60	110	1.70	730	300	780

Table 3: Results at 4 G/L Orange Peel Dosage

Time (min)	pH	Turbidity (NTU)	Fluoride (mg/L)	Chloride (mg/L)	Biochemical Oxygen Demand (mg/L)	Chemical Oxygen Demand (mg/L)
0	8.39	150	2.00	800	350	900
15	8.05	125	1.80	760	310	840
30	7.75	105	1.65	720	280	780
45	7.55	90	1.55	690	255	720
60	7.45	85	1.50	675	245	700
90	7.40	80	1.45	660	240	680

Table 4: Results at 6 G/L Orange Peel Dosage

Time (min)	pH	Turbidity (NTU)	Fluoride (mg/L)	Chloride (mg/L)	Biochemical Oxygen Demand (mg/L)	Chemical Oxygen Demand (mg/L)
0	8.39	150	2.00	800	350	900
15	7.95	105	1.65	720	280	780
30	7.55	80	1.45	660	230	700

45	7.30	60	1.30	600	190	620
60	7.10	50	1.15	560	170	540
90	7.00	45	1.05	530	160	500

Table 5: Results at 8 G/L Orange Peel Dosage

Time (min)	**pH**	**Turbidity (NTU)**	**Fluoride (mg/L)**	**Chloride (mg/L)**	**Biochemical Oxygen Demand (mg/L)**	**Chemical Oxygen Demand (mg/L)**
0	8.39	150	2.00	800	350	900
15	7.85	115	1.75	740	295	820
30	7.40	95	1.55	700	250	750
45	7.10	75	1.40	660	220	670
60	6.85	65	1.32	620	205	600
90	6.70	60	1.25	600	200	580

Table 6: Results at 10 G/L Orange Peel Dosage

Time (min)	**pH**	**Turbidity (NTU)**	**Fluoride (mg/L)**	**Chloride (mg/L)**	**Biochemical Oxygen Demand (mg/L)**	**Chemical Oxygen Demand (mg/L)**
0	8.39	150	2.00	800	350	900
15	7.95	95	1.60	700	260	750
30	7.55	70	1.40	640	210	670
45	7.30	50	1.20	580	170	590
60	7.10	40	1.05	520	140	500
90	7.00	30	0.90	470	120	430

Table 7: Results At 6g/L , 8g/L And 10g/L (Orange Peel Dosages at 90minutes)

Dosage (g/L)	**pH**	**Turbidity (NTU)**	**Fluoride (mg/L)**	**Chloride (mg/L)**	**Biochemical Oxygen Demand (mg/L)**	**Chemical Oxygen Demand (mg/L)**
6 g/L	7.00	60	1.25	600	200	580
8 g/L	6.70	45	1.05	530	160	500
10 g/L	6.45	30	0.90	470	120	430

Table 8: Percentage Removal at 90 Minutes Contact Time

Dosage (g/L)	**Turbidity (%)**	**Fluoride (%)**	**Chloride (%)**	**Biochemical Oxygen Demand (%)**	**Chemical Oxygen Demand (%)**
2	27.7	15.0	8.8	14.0	13.0
4	46.7	27.5	17.5	31.0	24.0
6	60.0	37.5	25.0	43.0	36.0
8	70.0	47.5	33.8	54.0	44.0
10	80.0	55.0	41.3	66.0	52.0

4.2 Discussion of Results

A consistent upward trend in pollutant removal was recorded as both adsorbent dosage and contact duration increased. At the minimum dose of 2 g/L, turbidity reduction reached only 27.7% after 90 minutes, whereas application of 10 g/L achieved an 80.0% reduction over the same period. This dose-dependent behaviour aligns with published findings attributing enhanced removal at higher loadings to a greater availability of adsorption sites per unit volume [5-6].The removal of fluoride increased from 15% at the lowest dosage of 2g/L to 55% at the highest dosage of 10g/L. This is due to the ion exchange capacity of the cellulose and pectin present in the orange peel. The fluoride ions are attracted to the orange peel due to electrostatic attraction. The removal of COD from 900 mg/L to 430 mg/L at the highest dosage of 10g/L indicates that 52.2% of the COD is removed.

Above 8 g/L, marginal gains in removal were noted, suggesting progressive saturation of binding sites on the adsorbent surface. Peak treatment performance was achieved within the 8–10 g/L range at a 90-minute equilibration period. The removal activity of orange peel arises from the reactive hydroxyl and carboxyl moieties present in its cellulose and pectin matrices, which drive pollutant uptake through ion exchange, hydrogen bonding, and surface complexation mechanisms [15]. The pH reduced gradually from 8.39, which is alkaline, to neutral at 6.45, corresponding to a 10g/L solution with a 90-minute contact time. This is a favorable trend for reuse and discharge standards. This is a result of the organic acids in orange peel, particularly citric and ascorbic acids.

5. Conclusion

This investigation successfully established the viability of orange peel powder as a low-cost, environmentally benign adsorbent for textile effluent remediation. The principal outcomes are summarised below:

Orange peel powder achieved measurable reductions in turbidity, fluoride, chloride, BOD, and COD concentrations in the textile effluent. Optimal treatment conditions were identified at a dosage of 8–10 g/L with a 90-minute contact period. At 10 g/L, peak removal efficiencies of 80% for turbidity, 55% for fluoride, 41.3% for chloride, 66% for BOD, and 52% for COD were recorded. Substantial pollutant reductions occurred between 2 and 6 g/L, with performance levelling beyond that range. Progressive neutralisation of the effluent pH was also noted with increasing adsorbent concentration. Utilising orange peel, a freely available agro-industrial residue, presents a cost-efficient and environmentally responsible approach to wastewater management. The approach aligns with circular economy principles by repurposing waste into a functional treatment resource. It is particularly well-suited for smaller textile operations with limited capital for conventional treatment infrastructure. Prospective studies should explore pilot-scale deployment and the integration of this approach with complementary treatment technologies.

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