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Treatment and Recycling Strategies for Greywater Originated from Bathrooms

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Abstract

Greywater treatment and reuse have emerged as sustainable and cost-effective alternatives to address water scarcity. Conventional treatment methods, such as membrane filtration and biological systems, are often limited by high cost and sensitivity to operational variations. This study investigates an integrated treatment approach combining coagulation–flocculation, filtration, and disinfection for greywater generated from laundry and bathing sources.

Alum and a high molecular weight polyelectrolyte were used as coagulant and flocculants, respectively. Process parameters were optimized using Response Surface Methodology (RSM). The optimum dosages were found to be 9 mg/L alum and 0.8 mg/L polyelectrolyte, with mixing speeds of 140 rpm (rapid) and 18 rpm (slow), and an optimal sedimentation time of 70 minutes. A dual media filtration system comprising sand and granular activated carbon (GAC) was optimized with a GAC-to-sand ratio of 0.6.

Column studies revealed that COD removal efficiencies ranged from 62.14% to 75.73% after 1 hour, while MBAS removal reached up to 93.81% under optimal conditions. The study demonstrates that the proposed hybrid system is efficient, economical, and suitable for decentralized greywater reuse applications.

Keywords: Greywater treatment, Coagulation–flocculation, GAC, RSM, COD, MBAS

Introduction

Water scarcity is a growing global concern driven by rapid population growth, urbanization, and increasing per capita water demand. The continuous depletion of freshwater resources has necessitated the exploration of alternative and sustainable water sources. In this context, greywater reuse has emerged as a viable option for reducing freshwater consumption, particularly for non-potable applications. Greywater is defined as domestic wastewater generated from activities such as bathing, laundry, and hand washing, excluding toilet effluent [1–3]. It accounts for approximately 50–80% of total household wastewater and contributes nearly 40% of the total Chemical Oxygen Demand (COD) load [4–6]. Despite containing impurities such as suspended solids, oils, grease, and detergents, greywater is relatively less contaminated than blackwater and is therefore easier to treat and reuse. Improper discharge of untreated greywater has led to the contamination of surface water bodies and depletion of groundwater resources, further aggravating water scarcity. Reuse of treated greywater can significantly reduce the demand for freshwater and lower the load on sewage systems. Studies indicate that about 80 liters per capita per day (lpcd) of greywater is generated (excluding kitchen wastewater), out of which approximately 25 lpcd can be reused for toilet flushing, leaving a substantial quantity available for other non-potable uses such as irrigation and cleaning [7,8]. However, greywater typically contains high concentrations of surfactants, particularly anionic compounds such as sodium dodecyl sulphate and linear alkylbenzene sulphonates, which are not effectively removed by conventional physical treatment methods alone [5,9]. Advanced treatment systems such as membrane filtration and biological processes have been explored, but their application is often limited by high costs, operational complexity, and sensitivity to shock loading [10–12]. Therefore, there is a need for cost-effective, efficient, and sustainable treatment technologies suitable for decentralized applications, especially in developing countries. The present study investigates an integrated treatment approach combining coagulation–flocculation, filtration, and disinfection processes for effective greywater treatment and reuse in non-potable applications.

Objective of the Study

1. Assessment of technical aspects of treatment and reuse of greywater from bath and laundry.
2. Optimization of the influencing operating parameters of the treatment process.
3. To evaluate the effectiveness of coagulation–flocculation using alum and polyelectrolyte (PE) for greywater treatment.

To investigate the performance and optimize the GAC to sand ratio in dual media filtration for efficient removal of COD and MBAS

Literature Review:

Greywater Treatment Technologies

Greywater treatment technologies are broadly classified into physical, chemical, biological, and physico-chemical methods. Generally, treatment systems include a pre-treatment step for solid–liquid separation followed by a disinfection stage.

Physical Treatment

Physical methods mainly involve filtration and sedimentation processes. Techniques such as sand filtration, membrane filtration, and soil filtration have been widely studied. COD removal efficiencies up to 82% and TDS up to 70% have been reported [14]. Membrane processes like ultrafiltration (UF) and nanofiltration (NF) provide higher removal efficiencies (up to 98% COD), but they are relatively costly [17,19]. However, physical treatment alone is often insufficient for removing dissolved pollutants like surfactants.

Chemical Treatment

Chemical processes include coagulation–flocculation, adsorption, ion exchange, and advanced oxidation. Coagulation combined with filtration and activated carbon has shown high efficiency, achieving up to 93% COD and 95% BOD removal [19,21]. Advanced oxidation processes and electrocoagulation also demonstrate significant pollutant removal. These methods are effective for removing dissolved and colloidal contaminants.

Biological Treatment

Biological systems such as rotating biological contactors (RBC), sequencing batch reactors (SBR), constructed wetlands (CW), and membrane bioreactors (MBR) are commonly used. These systems effectively reduce organic load, with BOD removal reaching below 5 mg/L in some cases [11]. However, biological processes are sensitive to shock loading and require careful operation.

Physico-Chemical Treatment

Combined physico-chemical methods integrate coagulation, filtration, and adsorption to enhance treatment efficiency. Systems using sand filtration and granular activated carbon (GAC) have achieved COD removal up to 90% [32]. Such integrated approaches are cost-effective and suitable for decentralized greywater treatment.

Methodology

Chemicals and Reagents: In the present study, alum (aluminum sulfate) was used as the coagulant, and a high molecular weight cationic polyelectrolyte (Poly Floc CP1155) was used as the flocculant, procured from GE Power and Water. Sulphuric acid used for the preparation of Chemical Oxygen Demand (COD) reagents was obtained from Merck Specialties Pvt. Ltd., Mumbai. Potassium dichromate and mercuric sulphate were used for preparing the COD digestion solution and were procured from Merck, India.

Granular Activated Carbon (GAC) with an average particle size of 1.5 mm (Loba Chemicals) was used as a filtration medium. Sand, collected from the Geotechnical Laboratory of the Civil Engineering Department, IIT Kharagpur, had an effective size of 0.3 mm and a uniformity coefficient of 2.7, as determined by sieve analysis. Gravel obtained from the water works plant of IIT Kharagpur was used as a supporting layer in the filtration column.

Standard potassium hydrogen phthalate (KHP) solution was prepared for COD calibration. Methylene blue reagent was used for determining Methylene Blue Active Substances (MBAS), while chloroform was used for extraction prior to spectrophotometric analysis. All chemicals used were of analytical grade.

Preparation of Synthetic Greywater

Synthetic greywater was prepared to simulate domestic greywater characteristics following standard procedures reported in the literature [42]. The solution was prepared by mixing 1.25 g of lauryl tryptose broth, 0.20 g of hair shampoo (Clinic Plus), 0.20 g of washing powder (Surf Excel), and 1.25 g (approximately 1 mL) of glycerol in 1 L of tap water. The mixture was homogenized using a magnetic stirrer.

Figure-1: Ingredients for preparation of synthetic greywater

The prepared synthetic greywater was stored at 5 °C prior to use. This synthetic wastewater was primarily used for optimizing the coagulation–flocculation and filtration processes based on COD and MBAS removal.

Coagulation–Flocculation Experiments

Coagulation–flocculation experiments were conducted using a standard jar test apparatus. Alum and polyelectrolyte were added in varying concentrations to determine the optimum dosage. Rapid mixing was performed at 140 rpm for proper dispersion of chemicals, followed by slow mixing at 18 rpm to facilitate floc formation. The optimum dosage was determined as 9 mg/L for alum and 0.8 mg/L for polyelectrolyte.

Sedimentation

After coagulation–flocculation, the treated samples were allowed to settle under quiescent conditions. Different settling times were evaluated, and the optimum sedimentation time was found to be 70 minutes based on maximum pollutant removal efficiency.

Dual Media Filtration

The supernatant obtained after sedimentation was passed through a laboratory-scale dual media filtration column consisting of sand and Granular Activated Carbon (GAC). Gravel was used as a supporting layer. The ratio of GAC to sand, bed depth, and hydraulic loading rate were optimized.

The optimum GAC-to-sand ratio was determined as 0.6.

Column Study

A continuous flow column study was conducted to evaluate the performance of the filtration system under varying flow rates (4, 8, and 12 mL/min). Effluent samples were collected at specific time intervals (1 hour and 24 hours) and analyzed for COD and MBAS removal efficiency.

Figure-2: Experimental set up for column study

Design of Experiment

Optimization of Combined Dose of Coagulant and Flocculants

Variables and Response

The coagulation–flocculation process is significantly influenced by the dosage of coagulant and flocculants, which governs floc formation efficiency and overall pollutant removal. In the present study, alum was used as the coagulant and a cationic polyelectrolyte as the flocculants. Both were applied simultaneously to enhance floc formation and reduce sludge production typically associated with alum-only coagulation.

Preliminary experiments were conducted to determine the working range of the variables. Based on these trials, the alum dose was varied from 6 to 12 mg/L, while the polyelectrolyte dose ranged from 0.6 to 1.0 mg/L. These two variables were selected as the key independent factors for optimization.

The treatment performance was evaluated in terms of removal efficiencies of Chemical Oxygen Demand (COD) and Methylene Blue Active Substances (MBAS), which were considered as the response variables. The objective of the experimental design was to maximize the removal of these parameters.

3^2 Factorial Design

A statistical experimental design approach was adopted using Design Expert software (Version 8.0.7.1, Stat-Ease Inc., USA) to optimize the process variables. A 3^2 factorial design was employed, consisting of two factors (alum dose and polyelectrolyte dose) at three levels each.

A second-order quadratic model was used to establish the relationship between the independent variables and the response. The generalized form of the model is given below:

$$Y=\beta_0+\sum_{i=1}^{k}\beta_i X_i+\sum_{i=1}^{k}\sum_{j=1}^{k}\beta_{ij}X_iX_j+\sum_{i=1}^{k}\beta_{ii}X_i^2+e$$

where Y represents the predicted response (COD or MBAS removal), X_i and X_j are the coded independent variables, β_0 is the intercept term, β_i represents linear coefficients, β_{ii} represents quadratic coefficients, β_{ij} represents interaction coefficients, k is the number of factors, and e is the random error. The experimental design matrix and corresponding responses were used to develop regression models and generate response surface plots. The optimized conditions were determined based on maximum removal efficiency of COD and MBAS.

Results And Discussions

The physicochemical characteristics of synthetic and real greywater are presented in Table 4.1. Real greywater showed significant variation due to temporal and source differences. The synthetic greywater had a COD of 1141 mg/L, consistent with reported literature. The mixed greywater used in this study exhibited characteristics comparable to previous studies, though slightly higher values were observed, likely due to variations in usage patterns and detergent content.

Table 4. 1: Greywater characteristics used during treatment experiments

Parameters	**Synthetic Greywater**	**Real Greywater**		
		Bath water	**Laundry water**	**Bath + Laundry**
PH	8.2	7.2	8.8	7.8
Conductivity (μS/cm)	1230	250	1072	634
TDS (mg/L)	625	123	525	308
Total solids (mg/L)	1008	350	1270	790
TSS (mg/L)	383	227	745	482
COD (mg/L)	1141	337.5	593.75	412.5
MBAS (mg/L)	274	70.25	124.03	94.16
Turbidity (NTU)	67.5	41.2	83.5	64.2

Table 4. 2: Optimization of RPM for rapid mixing Greywater COD = 585 mg/L

Sl. No.	**Alum Dose (mg/L)**	**PE Dose (mg/L)**	**Rapid Mixing (2 min) RPM**	**Slow Mixing (20 min) RPM**	**COD (mg/L)**	**% Removal**
1	9	0.8	60	20	455	22.22
2	9	0.8	120	20	435	25.64
3	9	0.8	180	20	435	25.64

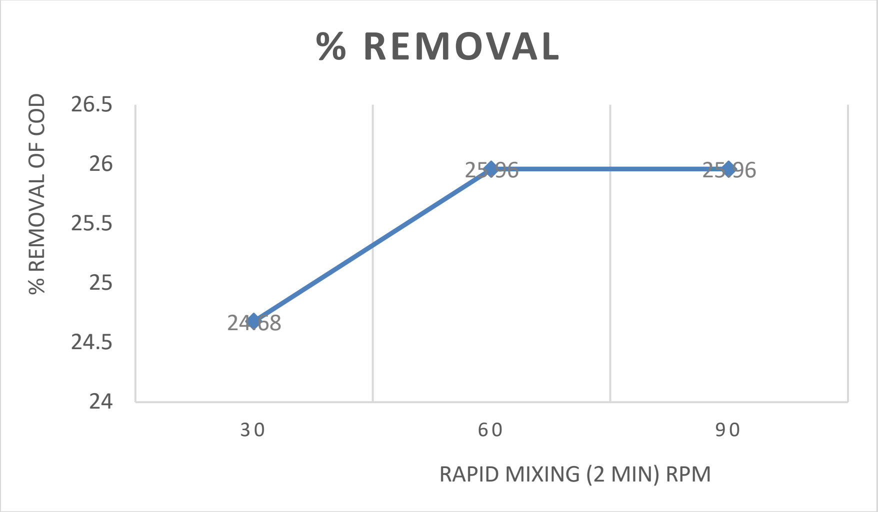

Figure-3: Optimization curve of RPM for rapid mixing

Table 4. 3: Optimization of RPM for slow mixing

Greywater COD = 587.5 mg/L Sl. No.	Alum Dose (mg/L)	PE Dose (mg/L)	Rapid Mixing (2 min) RPM	Slow Mixing (20 min) RPM	COD (mg/L)	% Removal
1	9	0.8	140	10	440	25.11
2	9	0.8	140	20	437.5	25.53
3	9	0.8	140	30	452.5	22.98

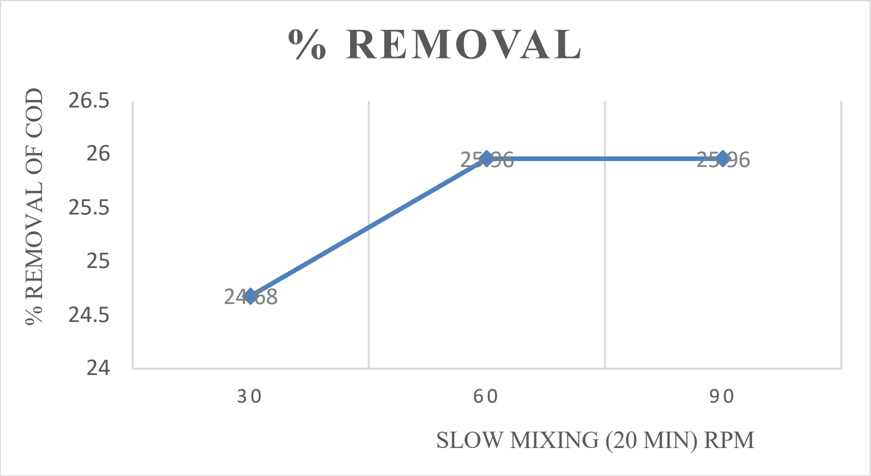

Figure-4: Optimization curve of RPM for slow mixing

Table 4. 4: Optimization of flocculated particles settlement time Greywater COD = 587.5 mg/L

Sl. No.	Alum Dose (mg/L)	PE Dose (mg/L)	Rapid Mixing (2 min) RPM	Slow Mixing (20 min) RPM	Floc Settlement Time (min)	COD (mg/L)	% Removal
1	9	0.8	140	20	30	442.5	24.68
2	9	0.8	140	20	60	435	25.96
3	9	0.8	140	20	90	435	25.96

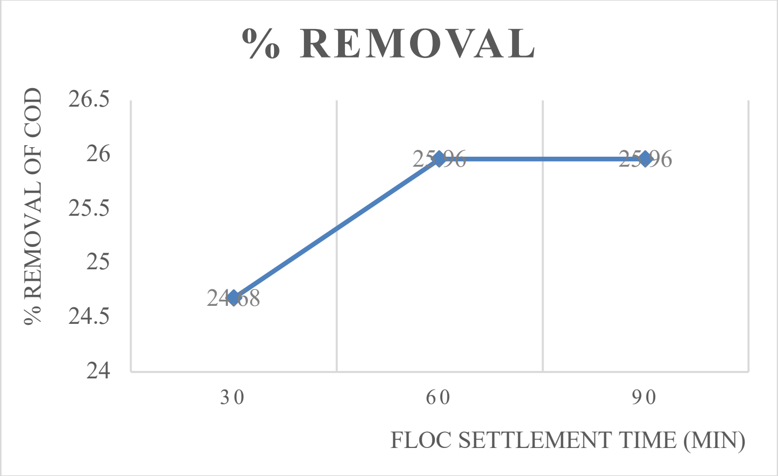

Figure-5: Optimization of flocculated curve for particles settlement time

4.1 RSM Study for Optimization of Coagulant and Flocculant Dose:- A two-factor, three-level factorial design was employed to optimize alum (A) and polyelectrolyte (B) dosages for COD and MBAS removal. The experimental results showed a variation of 6–25% in removal efficiency across different runs.

Quadratic models were developed to correlate the process variables with responses. The regression equations (in coded form) are:

$$qe\ (COD)=23.69+2.29A+2.44B-2.75A^2-10.94B^2+2.04AB$$

$$qe\ (MBAS)=24.24+2.11A+1.98B-3.90A^2-10.48B^2-2.14AB$$

ANOVA results indicated high model significance with large F-values, while the lack-of-fit was insignificant, confirming the adequacy and reliability of the developed models.

Table 4. 5: ANOVA for Response Surface Quadratic Model for COD removal efficiency

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remarks
Model	569.37	5	113.87	16.24	0.0010	Significant
A	31.71	1	31.71	4.52	0.0710	
B	35.80	1	35.80	5.10	0.0584	
A2	20.88	1	20.88	2.98	0.1281	
B2	330.52	1	330.52	47.13	0.0002	
AB	16.77	1	16.77	2.39	0.1659	
Residual	49.09	7	7.01			
Lack of Fit	39.95	3	13.32	5.83	0.0608	not significant
Pure Error	9.14	4	2.29	Pure Error	9.14	4
Cor Total	618.45	12		Cor Total	618.45	12

Table 4. 6: ANOVA for Response Surface Quadratic Model for MABS removal efficiency

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remarks
Model	573.64	5	114.73	37.46	573.64	Significant
A	26.91	1	26.91	8.79	26.91	
B	23.48	1	23.48	7.67	23.48	
A2	42.02	1	42.02	13.72	42.02	
B2	303.56	1	303.56	99.11	303.56	
AB	18.33	1	18.33	5.98	18.33	
Residual	21.44	7	3.06		21.44	
Lack of Fit	15.77	3	5.26	3.71	15.77	not significant
Pure Error	5.67	4	1.42		5.67	
Cor Total	595.08	12			595.08	

The high R^2 values [Table 4.7 for COD removal and MBAS removal] delineates the accuracy of the model. Adjusted and predicted R^2 values were in reasonable agreement with their corresponding R^2 values. A high value of 'adequate precision' (signal to noise ratio) for both cases indicates that the model is unaffected by noise data.

Table 4. 7: Regression coefficients of original and reduced model of 32 full factorial design for COD and MBAS removal

Regression coefficient	**Original and reduced model of 3^2 full factorial design for COD removal**	**Original and reduced model of 3^2 full factorial design for MBAS removal**
R^2 (Coefficient of Determination)	0.92	0.96
Adjusted R^2	0.86	0.94
Predicted R^2	0.33	0.72
Adequate Precision	9.11	14.02

The graphical method mostly comprise of the analysis of residual of the model. The plot of studentized residual versus predicted value established the adequacy of the model.

4.2 RSM Study for Column Operation Optimization

A three-factor, three-level design (FCCD) was used to optimize carbon-to-sand ratio (A), initial COD concentration (B), and flow rate (C) for COD and MBAS removal. The removal efficiencies varied from 42–92% (1 h) and 2–30% (24 h) for COD, and 51–93% (1 h) and 1–29% (24 h) for MBAS.

Quadratic models were developed to relate variables with responses. The regression equations (coded form) are: **At 1 h:**

$$qe\,(COD)=68.78+9.76A-5.15B-10.97C-1.63A^2+1.08B^2-0.5C^2-0.21AB-0.35AC-0.42BC$$

$$qe\,(MBAS)=72.97+8.13A-5.36B-9.51C-3.8A^2+1.53B^2-1.08C^2-2.14AB-0.62AC+1.36BC$$

At 24 h:

$$qe\,(COD)=10.3+5.13A-3.25B-5.31C-0.41A^2+2.47B^2+1.39C^2-0.41AB-1.45AC+0.88BC$$

$$qe\,MBAS)=11.62+5.67A-2.01B-5.76C+0.02A^2-0.51B^2+2.41C^2-0.81AB-0.63AC+0.53BC$$

ANOVA results confirmed the significance of the models with high F-values, while insignificant lack-of-fit indicated good agreement between experimental and predicted results.

Table 4. 8: ANOVA for Response Surface Quadratic Model for COD removal efficiency at 1 h

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remark
Model	2434.684	9	270.5204	13.49557	0.0002	Significant
A	951.7954	1	951.7954	47.48263	< 0.0001	
B	264.8132	1	264.8132	13.21085	0.0046	
C	1203.848	1	1203.848	60.05688	< 0.0001	
A2	7.314627	1	7.314627	0.364908	0.5592	
B2	3.202202	1	3.202202	0.15975	0.6978	
C^2	0.690002	1	0.690002	0.034422	0.8565	
AB	0.34445	1	0.34445	0.017184	0.8983	
AC	0.98	1	0.98	0.04889	0.8295	
BC	1.42805	1	1.42805	0.071242	0.7950	
Residual	200.4513	10	20.04513			
Lack of Fit	182.1048	5	36.42095	9.92584	0.0124	not significant
Pure Error	18.34653	5	3.669307			
Cor Total	2635.135	19				

Table 4. 9: ANOVA for Response Surface Quadratic Model for MBAS removal efficiency at 1 h

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remarks
Model	2007.154	9	223.0171	8.906542	0.0010	Significant
A	691.0597	1	691.0597	27.59856	0.0004	
B	286.9745	1	286.9745	11.46078	0.0069	
C	904.5912	1	904.5912	36.12628	0.0001	
A2	39.88118	1	39.88118	1.592718	0.2356	
B2	6.452784	1	6.452784	0.257702	0.6227	
C^2	3.196809	1	3.196809	0.12767	0.7283	
AB	36.6368	1	36.6368	1.463149	0.2542	
AC	3.15005	1	3.15005	0.125802	0.7302	
BC	14.96045	1	14.96045	0.597469	0.4574	
Residual	250.397	10	25.0397			
Lack of Fit	214.0336	5	42.80673	5.885971	0.0371	not significant
Pure Error	36.36335	5	7.27267			
Cor Total	2257.551	19				

Table 4. 10: ANOVA for Response Surface Quadratic Model for COD removal efficiency at 24 h

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remarks
Model	727.6303	9	80.84781	11.43546	0.0004	Significant
A	263.5796	1	263.5796	37.28181	0.0001	
B	105.8201	1	105.8201	14.96764	0.0031	
C	281.5364	1	281.5364	39.8217	< 0.0001	
A2	0.452082	1	0.452082	0.063944	0.8055	
B2	16.7713	1	16.7713	2.372204	0.1545	
C2	5.348082	1	5.348082	0.756455	0.4048	
AB	1.353013	1	1.353013	0.191376	0.6711	
AC	16.79101	1	16.79101	2.374992	0.1543	
BC	6.248113	1	6.248113	0.883759	0.3693	
Residual	70.69924	10	7.069924			
Lack of Fit	63.66504	5	12.73301	9.050786	0.0152	not significant
Pure Error	7.0342	5	1.40684			
Cor Total	798.3295	19				

Table 4. 11 ANOVA for Response Surface Quadratic Model for MBAS removal efficiency at 24 h

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remarks
Model	726.8308	9	80.75898	19.5186	< 0.0001	Significant
A	320.9223	1	320.9223	77.56353	< 0.0001	
B	40.20025	1	40.20025	9.715978	0.0109	
C	331.6608	1	331.6608	80.15893	< 0.0001	
A2	0.000736	1	0.000736	0.000178	0.9896	
B2	0.725511	1	0.725511	0.175348	0.6843	

C^2	16.05674	1	16.05674	3.880744	0.0771	
AB	5.28125	1	5.28125	1.276423	0.2849	
AC	3.20045	1	3.20045	0.773515	0.3998	
BC	2.31125	1	2.31125	0.558605	0.4720	
Residual	41.3754	10	4.13754			
Lack of Fit	37.39045	5	7.478091	9.382917	0.0141	Not significant
Pure Error	3.98495	5	0.79699			
Cor Total	768.2062	19				

The high R^2 values [Table 4.12 for COD removal and MBAS removal] delineates the accuracy of the model. Adjusted and predicted R^2 values were in reasonable agreement with their corresponding R^2 values. A high value of 'adequate precision' (signal to noise ratio) for both cases indicates that the model is unaffected by noise data.

Table 4. 12: Regression coefficient

Regression coefficients of	**FCCD for COD removal at 1 h**	**FCCD for MBAS removal at 1 h**	**FCCD for COD removal at 24 h**	**FCCD for MBAS removal at 24 h**
R2	0.923	0.889	0.911	0.946
Adjusted R^2	0.855	0.789	0.832	0.898
Predicted R^2	0.533	0.237	0.352	0.601
Adequate precision	16.345	13.103	14.566	18.673

The graphical method mostly comprise of the analysis of residual of the model. The plot of studentized residual versus predicted value established the adequacy of the model.

Treatment and Removal Efficiencies

Real greywater was treated using optimized process parameters. The initial COD and MBAS concentrations were 303.75 mg/L and 117.20 mg/L, respectively. After coagulation–flocculation, these values decreased to 257.50 mg/L (COD) and 103.60 mg/L (MBAS).

The treated water was further passed through a dual media filtration column consisting of sand (12.5 cm) and GAC (7.5 cm) with a GAC:sand ratio of 0.6 and total depth of 20 cm. Filtration was carried out at flow rates of 4, 8, and 12 mL/min (0.76, 1.52, and 2.28 $m^3/m^2 \cdot h$, respectively).

The corresponding COD and MBAS removal efficiencies at different flow rates are presented in the subsequent tables.

Table 4. 13: Optimized influencing parameters for treatment

Parameter	**Optimized Value**
Rapid Mixing	140 RPM
Slow Mixing	18 RPM
Floc Settlement Time	70 min
Coagulant–Flocculant Dose	9 mg/L Alum + 0.8 mg/L PE
GAC: Sand Ratio	0.6

Table 4. 14: Result of COD and MBAS removal for 24 h column study at flow rate 4 ml/min

	Result of COD removal for 24 h column study at flow rate 4 ml/min Influent COD, Co = 257.5 mg/l			Result of MBAS removal for 24 h column study at flow rate 4 ml/min Influent MBAS, Co = 103.60 mg/l		
Time (h)	**Effluent COD, C_e (mg/L)**	**C_e/C_0**	**% Removal**	**Effluent COD, C_e (mg/L)**	**C_e/C_0**	**% Removal**
1	62.5	0.24	75.73	62.5	0.24	75.73
3	90	0.35	65.05	90	0.35	65.05
6	92.5	0.36	64.08	92.5	0.36	64.08
12	110	0.43	57.28	110	0.43	57.28
24	145	0.56	43.69	145	0.56	43.69

Table 4.15: Result of COD & MBAS removal for 24 hr column study at flow rate 8 ml/min

	Result of COD removal for 24 hr column study at flow rate 8 ml/min Influent COD, Co = 257.5 mg/l			Result of MBAS removal for 24 h column study at flow rate 8 ml/min Influent MBAS, Co = 103.60 mg/l		
Time (h)	**COD, Ce (mg/l)**	**Ce/Co**	**% Removal**	**MBAS, Ce (mg/l)**	**Ce/Co**	**% Removal**
1	77.5	0.30	69.90	19.16	0.18	81.50
3	115	0.45	55.34	25.11	0.24	75.76
6	147.5	0.57	42.72	31.92	0.31	69.19
12	162.5	0.63	36.89	55.21	0.53	46.71
24	232.5	0.90	9.71	85.58	0.83	17.39

Table 4. 16: Result of COD removal for 24 hr column study at flow rate 12 ml/min

Influent COD, Co = 257.5 mg/l

	Result of COD removal for 24 hr column study at flow rate 12 ml/min Influent COD, Co = 257.5 mg/l			Result of MBAS removal for 24 h column study at flow rate 12 ml/min Influent MBAS, Co = 103.60 mg/l		
Time (h)	**COD, Ce (mg/l)**	**Ce/Co**	**% Removal**	**MBAS, Ce (mg/l)**	**Ce/Co**	**% Removal**
1	97.5	0.38	62.14	23.91	0.23	76.92
3	137.5	0.53	46.60	30.61	0.30	70.46
6	160	0.62	37.86	39.36	0.38	62.01
12	205	0.80	20.39	62.01	0.60	40.14
24	245	0.95	4.85	97.03	0.94	6.35

Conclusions

A laboratory-scale study was conducted for greywater treatment using a physico-chemical approach comprising coagulation–flocculation followed by dual media filtration. Alum (9 mg/L) and polyelectrolyte (0.8 mg/L) were used as coagulant and flocculant, respectively. The filtration unit consisted of sand and granular activated carbon (GAC) with a total bed depth of 20 cm, and GAC:sand ratios of 0.2, 0.4, and 0.6 were evaluated. Results indicated that higher GAC proportion (0.6) yielded better treatment performance.

The optimized system was applied to real greywater at flow rates of 4, 8, and 12 mL/min (0.76, 1.52, and 2.28 $m^3/m^2 \cdot h$). COD removal efficiencies were 75.73%, 69.90%, and 62.14% after 1 h, and 43.69%, 9.71%, and 4.85% after 24 h, respectively. Corresponding MBAS removal efficiencies were 93.81%, 81.50%, and 76.92% after 1 h, and 32.85%, 17.39%, and 6.35% after 24 h.

The results demonstrate that the proposed system is effective for greywater treatment. Further pilot-scale studies are recommended to assess field applicability, cost-effectiveness, and long-term sustainability.

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