IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

TREATMENT AND RECYCLING STRATEGIES FOR GREYWATER ORIGINATED FROM BATHROOMS

Sumit Bansal[1], Dr. Ravi Kant Pareek[2]

1. Sumit Bansal, M.tech Scholar , Vivekananda global University, Jaipur, Rajasthan, India
2. Dr. Ravi Kant Pareek, Associate Professor, Vivekananda global University, Jaipur, Rajasthan, India

Abstract: Treatment of greywater for reuse has attained importance in the recent years, asits reuse can be a cost-effective alternative source for water. Many treatment systems were studied and optimized considering the minimum energy requirement and operational feasibility. Present study mostly focused on the optimization of process parameters. In the coagulation-flocculation process, the coagulant and flocculant dose were optimized with RSM and combination of the doses were applied (9 mg/l alum + 0.8 mg/l PE). The agitation rate of mixing was also optimized (18 RPM for slow mixing and 140 RPM for fast mixing). Sedimentation time was optimized and the optimum time found as 70 minutes. The dual media filtration with sand and GAC were optimized keeping the consideration of cost and efficiency, the GAC to sand depth ratio, initial COD concentration and flow rate was optimized using RSM (RSM suggest a GAC: sand =0.6). The treatment of real greywater was performed and the parameters measured were, COD and MBAS. Column study was carried out at optimized influencing parameters. The COD removal efficiency at flow rate 4 ml/min (0.76 m3/m2/h), 8 ml/min (1.52 m3/m2/h) and 12 ml/min (2.28 m3/m2/h) was observed as 75.73%, 69.90% and 62.14% after 1 h and 43.69%, 9.71% and 4.85% after 24 h, respectively. The MBAS removal at the same flow rate was observed as 93.81%, 81.50% and 76.92% after 1 h and 32.85%, 17.39% and 6.35% after 24 h, respectively.

Index Terms: Chemical Oxygen Demand, Methylene Blue active Substances, Potassium Hydrogen Phthalate, Granular Activated Charcoal, Polyelectrolyte, Rotation per Minute, Constructed Wetland, membrane Bio-Reactor

1 Introduction

Water scarcity is the common problem throughout the world. The scarcity of water is getting increased day by day due to increase in water demand and decrease in fresh water sources. Increase in population and change in lifestyle is leading to the increase in water demand. Change in lifestyle is mainly due to change in income and per capita demand of water generally,increases with income. To fulfill this demand greywater can be successfully treated to use,potentially as an alternate source. Biological treatment requires post treatment like filtration and disinfection before use. The chemical processes involved oxidation, coagulation which is not much efficient as well as they are costlier. Present study is based on physiochemical method of treatment strategy for recycling of greywater. The process involved coagulation with alum and flocculation with PE (poly Floc CP1155) as flocculant which is able to reduce the amount of sludge produced. Now the settled water after this process is filtered on sand bed followed by GAC adsorption. The adopted method is same as traditional but flocculant wasused along with GAC adsorption. It may reduce the cost of treatment. The main gap in the research is to find a sustainable treatment process which can be adopted by everyone and everywhere. Experimental studies were conducted for both synthetic greywater and real greywater. Synthetic greywater was prepared in laboratory using surf, shampoo, glycerol and lauryl tryptose broth. The synthetic greywater was mainly used in optimization of the process parameters of coagulation, flocculation and filtration. Real greywater sample was collected from washing machine outlet and bath outlet.

2 Materials:

2.1 Chemicals and reagents

In present study, alum is used as coagulant and high molecular weight cationic polyelectrolyte (Poly Floc CP1155) used as flocculant, was obtained from GE Power and Water. Sulphuric acid used to prepare COD reagent and was obtained from Merck specialties Pvt. Ltd., Worly, Mumbai. Potassium dichromate and mercuric sulphate were used to prepare digestion solution for COD determination and obtained from Merck, India. Granular Activated Charcoal (average size of 1.5 mm) used as filter media was supplied by Loba chemicals. Sand was collected from geotechnical lab of Civil engineering department, IIT Kharagpur, having effective size of 0.3 mm and uniformity co-efficient was 2.7 (analyzed by sieve analysis method).

2.2 Preparation of synthetic greywater

The synthetic greywater has been prepared in this study was in similar way as mentioned by literature [42]. In details the synthetic greywater solution was prepared by mixing 1.25 g lauryl tryptose broth (Supplied by HIMEDIA Laboratories Pvt. Ltd., Mumbai), 0.20 g hair shampoo (Clinic plus), 0.20 g washing powder (Surf excel), 1.25 g (Approx. 1ml) glycerol (Supplied by Merck specialties Pvt. Ltd., Worly, Mumbai) in 1 L tap water (Treated water supplied in IIT, Kharagpur campus) and mixed properly using magnetic stirrer. Then the as synthesized artificial greywater was stored in freeze at 5°C temperature.

2.3 Source of real greywater sample

The real greywater sample used in this study was collected from MMM hall of residence in IIT, Kharagpur campus. Laundry water from washing machine and bath water were collected separately and it was mixed in the ratio of 5:6 in order to make a greywater similar to bathrooms greywater.

2.4 Instrumental

For continuous study a total depth of 20 cm for dual filter media and 5 cm depth of gravels was arranged in the glass column (2.0 cm. i.d. and 50 cm length). There were three types of different column in respect of GAC: Sand bed depth. The varying depth ratios are: 0.2, 0.4 and 0.6 and the total depths were kept same i.e. 20 cm. Experiments were designed for different hydraulic loadings 0.76- 2.28 m3/m2/h i.e. 4-12 ml/minutes.

2.5 Procedure

In order to evaluate the process performance, coagulation (using alum as coagulant and PE as flocculant), sand and activated carbon filtration experiments were performed on both synthesized and collected real greywater samples. Samples of greywater and effluent after each process were collected and analyzed. The alum and PE doses were optimized separately. The role of variation of dosages (2.5, 5, 10, 15, 20, 25 and 30 mg/ L for Alum and 0.2, 0.4, 0.6, 0.8 and 1.0 mg /L for polyelectrolyte) on process performance was evaluated using jar test apparatus (supplied by Reico Equipment & Instrument Pvt. Ltd.). For coagulation experiments, 400 mL of greywater samples were transferred in flasks. Samples were agitated at 120 rpm for 2 min (rapid mixing) followed by a lower agitation speed at 20 rpm for 20 min (gentle mixing), then the system are allowed to settle for 60 min. The optimized dose was used for further experiments to optimize combined dose of alum and PE and then different process parameters of dual media filtration.

3 Results & Discussions

The physicochemical characteristics for both synthetic and real greywater are presented in Table 3.1.

Table 3.1 : 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	337.50	593.75	412.50
MBAS (mg/L)	274	70.25	124.03	94.16
Turbidity (NTU)	67.5	41.2	83.5	64.2

Coagulation and flocculation experiment

3.2 Optimization of coagulation and flocculation process parameters

The optimum agitation speed for rapid mixing was found as 140 RPM. Optimum speed for slow mixing was found as 18 RPM and optimum settlement time was 70 minutes. All the above findings are presented in following tables and figures.

Table 3.2 : Optimization of RPM for rapid mixing

Greywater COD = 585 mg/L

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

Table 3. 3 : Optimization of RPM for slow mixing

Greywater COD = 587.5 mg/L

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

Table 3.4 : ANOVA for Response Surface Quadratic Model for COD removalefficiency

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	
A^2	20.88	1	20.88	2.98	0.1281	
B^2	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			
Cor Total	618.45	1 2				

Table 3.5 : ANOVA for Response Surface Quadratic Model for MABS removalefficiency

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	
A^2	42.02	1	42.02	13.72	42.02	
B^2	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 3.6 for COD removal and Table 3.7 for MBAS removal] delineatesthe accuracy of the model.

Table 3.6 : Regression coefficients of original and reduced model of 3^2 full factorial design for COD removal

Regression coefficient	
R^2	0.92
Adjusted R^2	0.86
Predicted R^2	0.33
Adequate precision	9.11

Table 3.7 : Regression coefficients of original and reduced model of 3^2 full factorialdesign for MBAS removal

Regression coefficient	
R^2	0.96
Adjusted R^2	0.94
Predicted R^2	0.72
Adequate precision	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 [Fig. 3.6 forCOD removal and Fig. 3.7 for MBAS removal].

Figure 3.1 : Normal plot of residual of RSM model for adsorption of COD removal

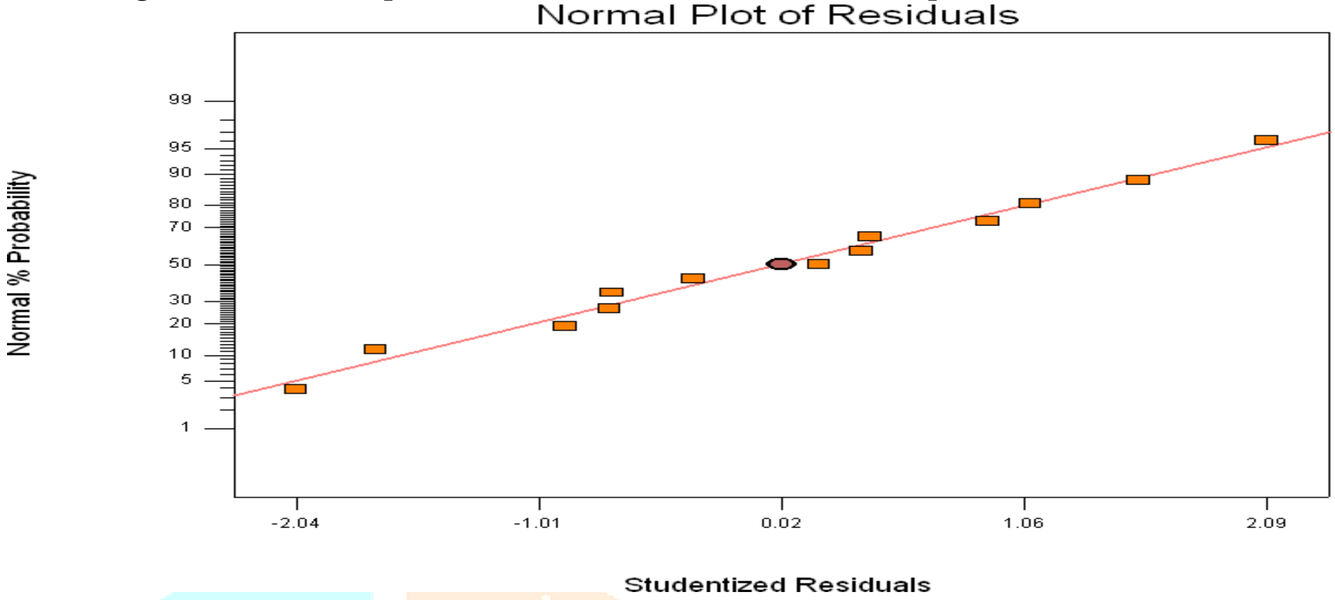
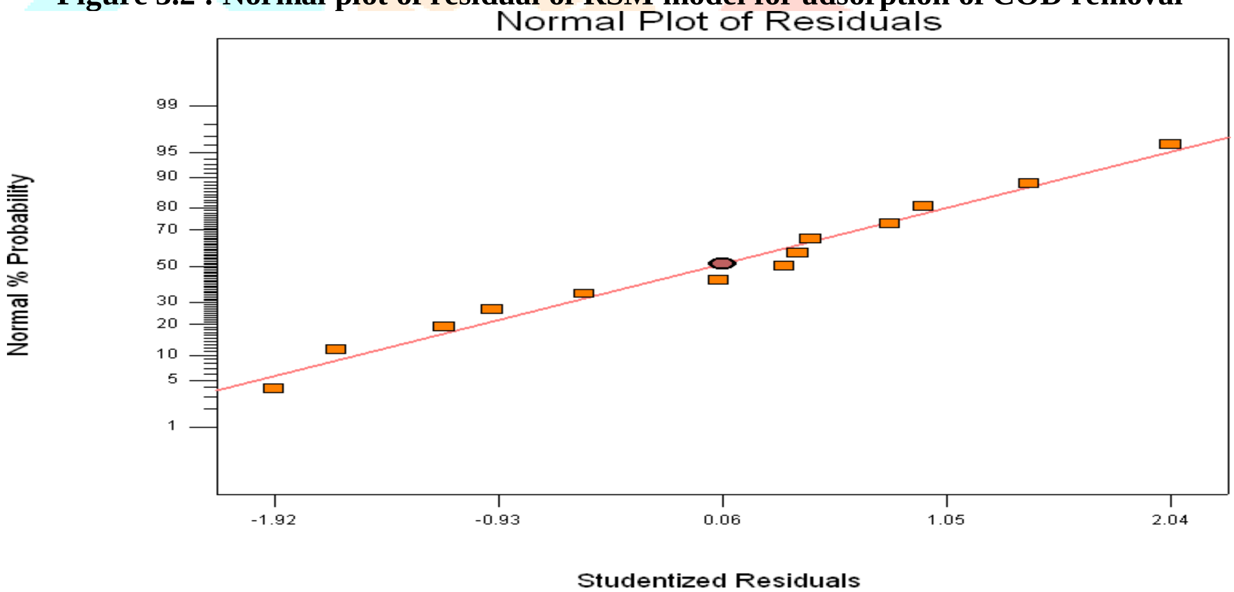


Figure 3.2 : Normal plot of residual of RSM model for adsorption of COD removal



Influence of Parameters

Individual effect of the parameter clarified by perturbation curves [Fig. 3.6 for COD removal and Fig. 3.7 for MBAS removal] demonstrates both alum and PE dose attains optima on both the responses around central value of the factors as shown in [Fig. 3.6 for COD removal and Fig. 3.7 for MBAS removal].

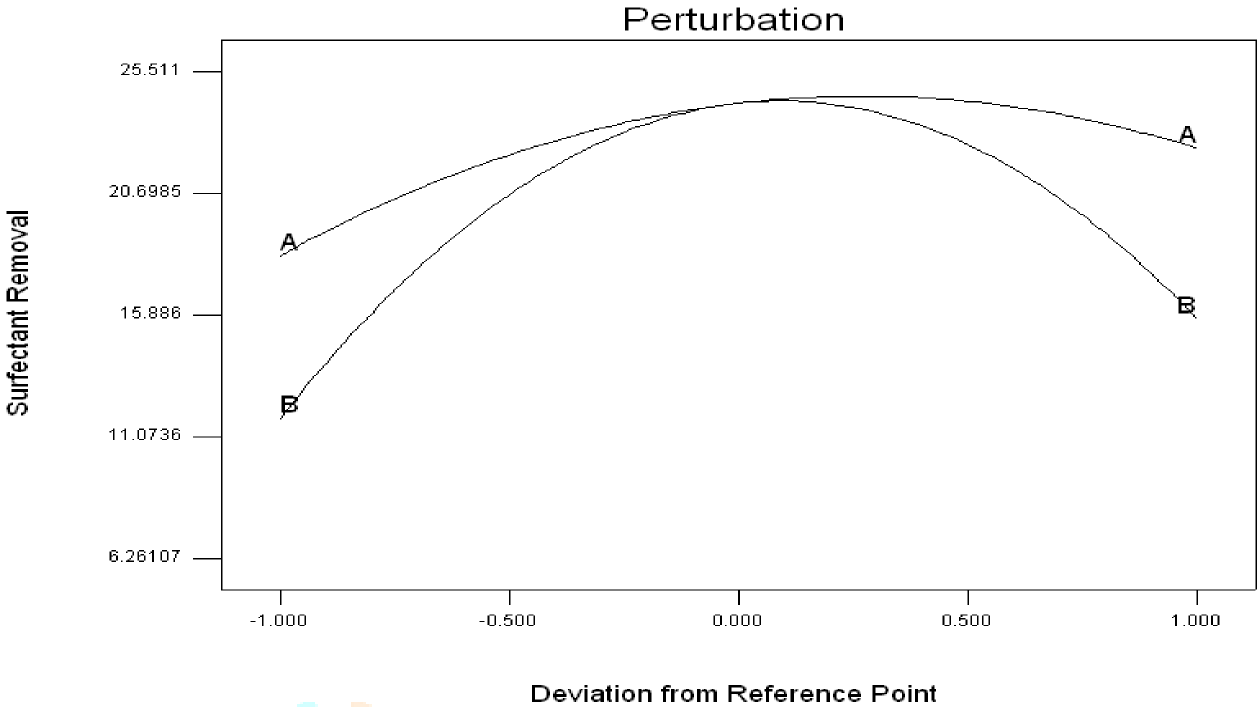


Table 3.8 : ANOVA for Response Surface Quadratic Model for COD removal efficiency at 1 h

Source	Sum of Square	DF	Mean Squares	F Value	Prob > F	Remarks
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	
A^2	7.314627	1	7.314627	0.364908	0.5592	
B^2	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 3.9 : ANOVA for Response Surface Quadratic Model for MBAS removalefficiency at 1h

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	
A^2	39.88118	1	39.88118	1.592718	0.2356	
B^2	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 3.10 ANOVA for Response Surface Quadratic Model for MBAS removalefficiency 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	
A^2	0.000736	1	0.000736	0.000178	0.9896	
B^2	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 3.12 for COD removal and Table 3.13 for 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 tonoise ratio) for both cases indicates that the model is unaffected by noise data.

Table 3.11 : Regression coefficients of FCCD for COD removal at 1 h

Regression coefficient	
R^2	0.923
Adjusted R^2	0.855
Predicted R^2	0.533
Adequate precision	16.345

Table 3.12 : Regression coefficients of FCCD for MBAS removal at 1 h

Regression coefficient	
R^2	0.889
Adjusted R^2	0.789
Predicted R^2	0.237
Adequate precision	13.103

Table 3.13 : Regression coefficients of FCCD for COD removal at 24 h

Regression coefficient	
R^2	0.911
Adjusted R^2	0.832
Predicted R^2	0.352
Adequate precision	14.566

Table 3.14 : Regression coefficients of FCCD for MBAS removal at 24 h

Regression coefficient	
R^2	0.946
Adjusted R^2	0.898
Predicted R^2	0.601
Adequate precision	18.673

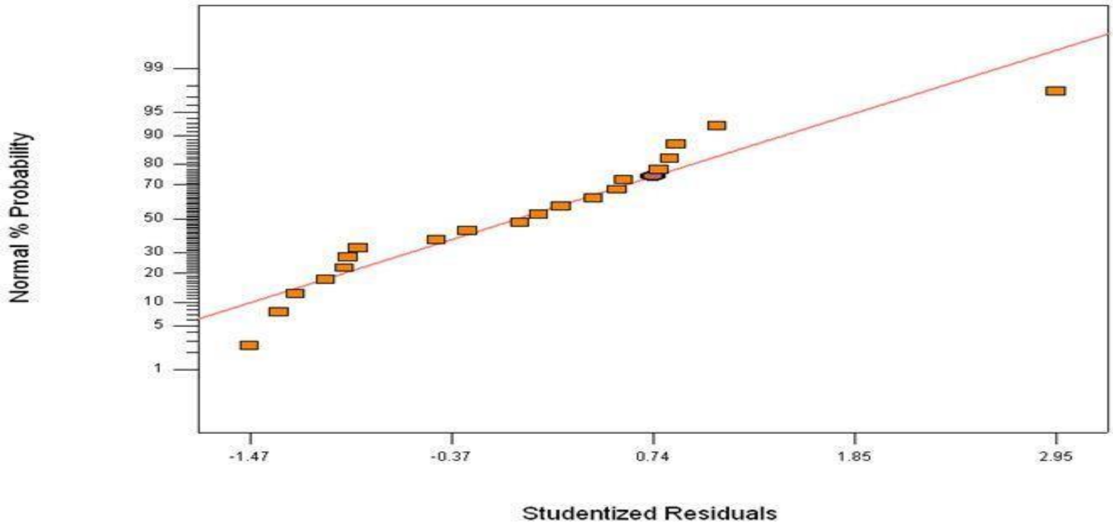


Figure 3.3 : Normal plot of residual of RSM model of COD removal at 1 h

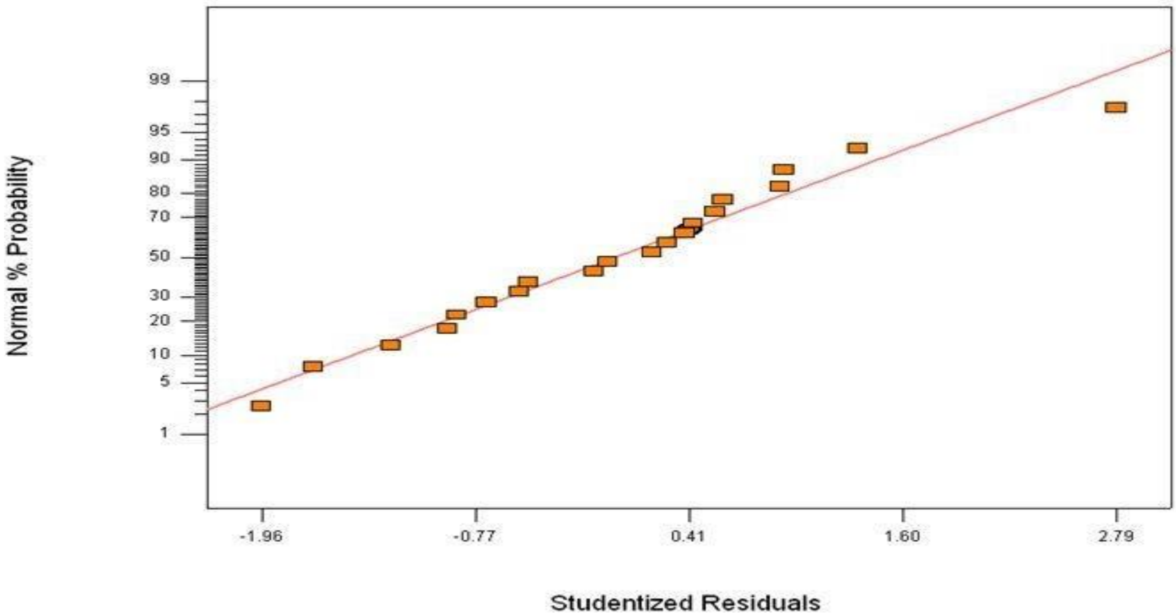


Figure 3.4 : Normal plot of residual of RSM model of MBAS removal at 1 h

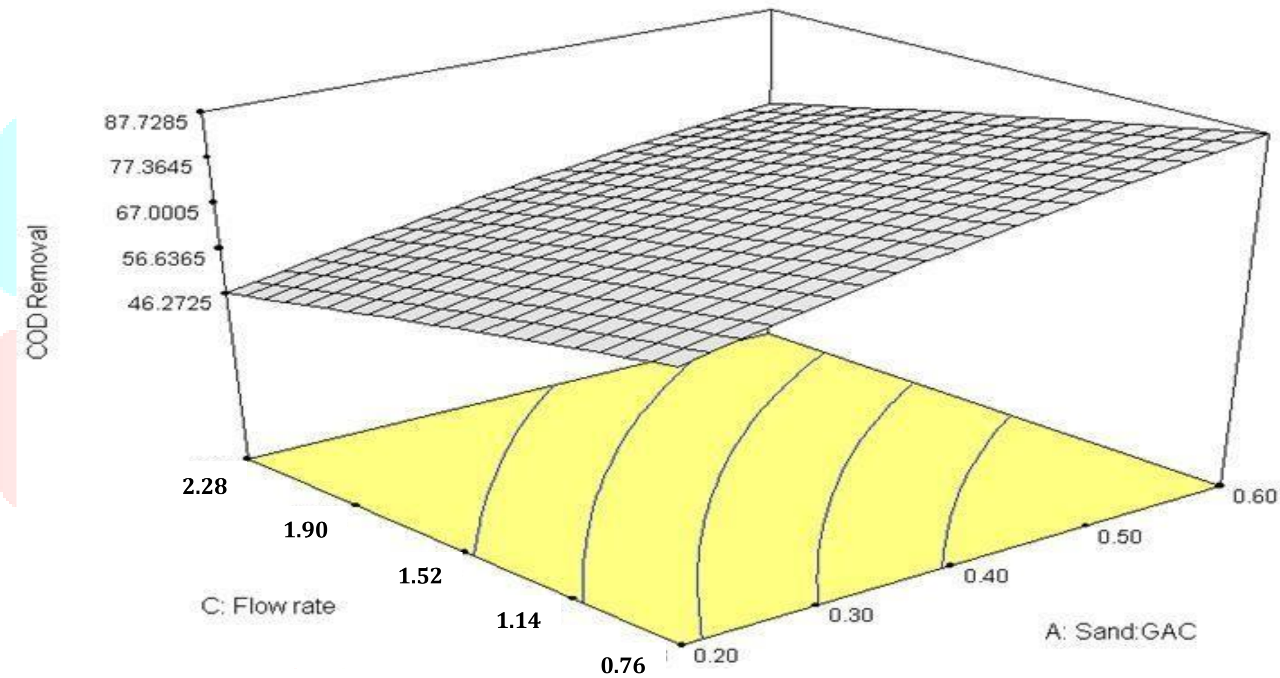


Figure 3.5 : Three dimensional response surface showing combined effect of Sand andGAC ratio and Initial COD concentration on COD removal at 1 h

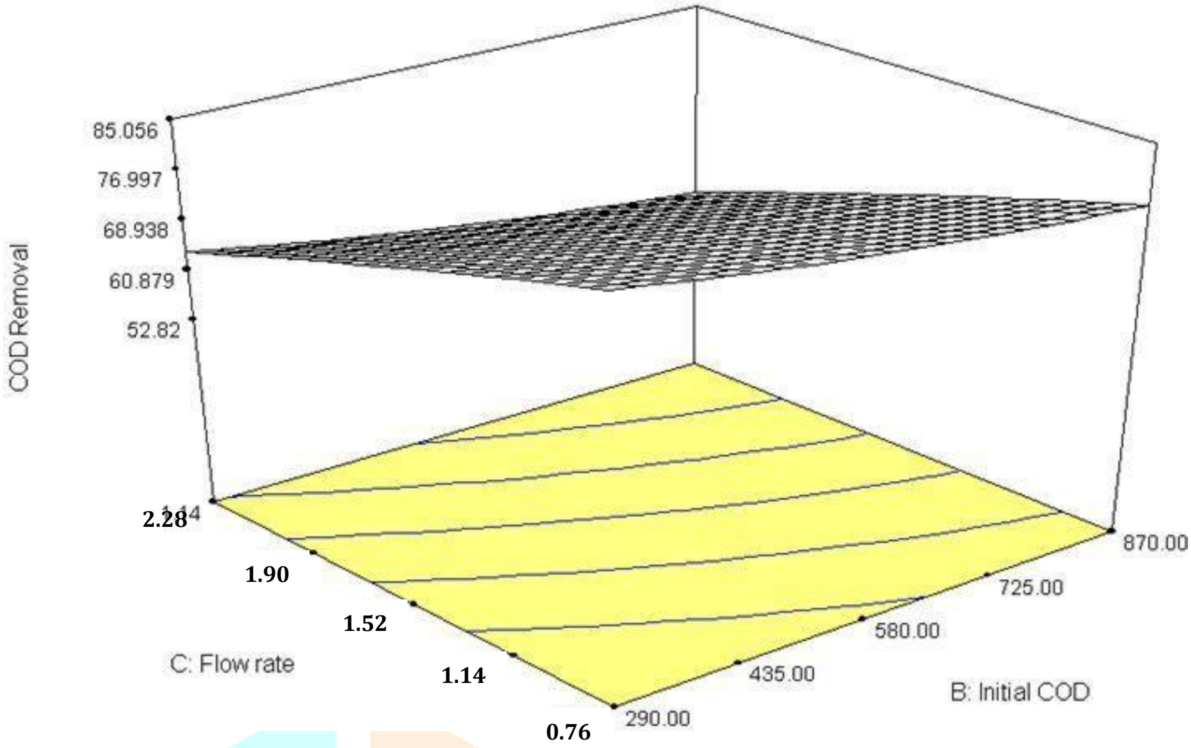


Figure 3.6 : Three dimensional response surface showing combined effect of Sand andGAC ratio and Flow rate on COD removal at 1 h

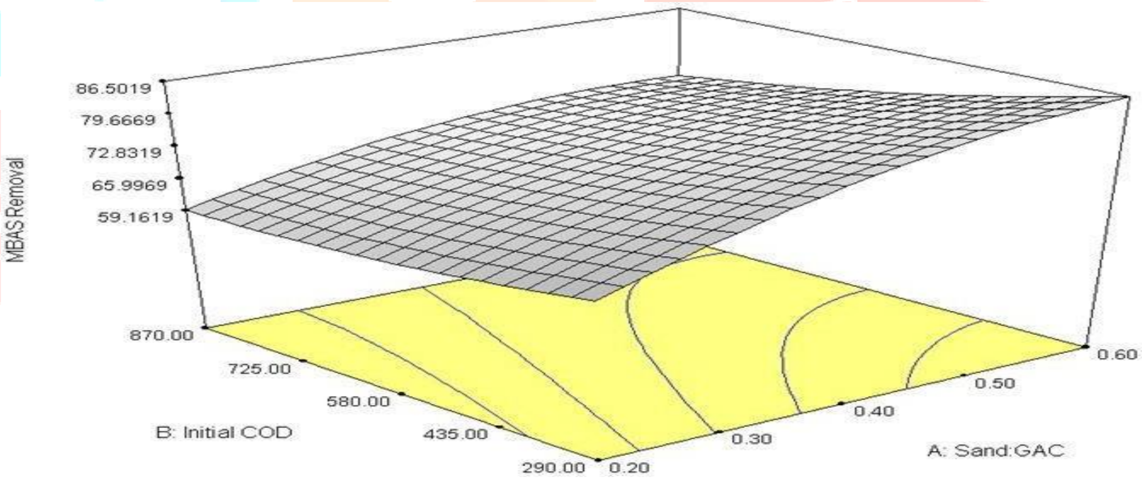


Figure 3.7 : Three dimensional response surface showing combined effect of flow rateand Initial COD concentration on COD removal at 1 h

Treatment and removal efficiencies

Table 3.15 : 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	0.6

Table 3.16 : Result of COD removal for 24 h column study at flow rate 4 ml/min

Influent COD, Co = 257.5 mg/l			
Time (h)	COD, Ce (mg/l)	Ce/Co	% Removal
1	62.5	0.24	75.73
3	90	0.35	65.05
6	92.5	0.36	64.08
12	110	0.43	57.28
24	145	0.56	43.69

Table 3.17 : Result of COD removal for 24 hr column study at flow rate 8 ml/min

Influent COD, Co = 257.5 mg/l			
Time (h)	COD, Ce (mg/l)	Ce/Co	% Removal
1	77.5	0.30	69.90
3	115	0.45	55.34
6	147.5	0.57	42.72
12	162.5	0.63	36.89
24	232.5	0.90	9.71

Table 3.18 : Result of MBAS removal for 24 h column study at flow rate 8 ml/min

Influent MBAS, Co = 103.60 mg/l			
Time (h)	MBAS, Ce (mg/l)	Ce/Co	% Removal
1	19.16	0.18	81.50
3	25.11	0.24	75.76
6	31.92	0.31	69.19
12	55.21	0.53	46.71
24	85.58	0.83	17.39

Table 3.19 : Result of COD removal for 24 hr column study at flow rate 12 ml/min

Influent COD, Co = 257.5 mg/l			
Time (h)	COD, Ce (mg/l)	Ce/Co	% Removal
1	97.5	0.38	62.14
3	137.5	0.53	46.60
6	160	0.62	37.86
12	205	0.80	20.39
24	245	0.95	4.85

4 SUMMARY AND CONCLUSION

The treatment of real greywater samples were performed, starting with coagulation- flocculation with a combined dose of 9 mg/l alum and 0.8 mg/l of PE and then filtration on dual filter media (bed depth 20 cm) with a GAC : sand value 0.6. Filtration experiments were run at different flow rate of 4 ml/min (0.76 m3/m2/h), 8 ml/min (1.52 m3/m2/h) and 12 ml/min (2.28 m3/m2/h) and removal efficiency of COD was observed as 75.73%, 69.90% and 62.14% after 1 h, whereas 43.69%, 9.71% and 4.85% after 24 h, respectively. The MBAS removal at the same flow rate was observed as 93.81%, 81.50% and 76.92% after 1 h and 32.85%, 17.39% and 6.35% after 24 h, respectively. Above results concludes that present study showing a good removal and it can be used for treatment. Sustainable utilization of the technology can be confirmed by a pilot scale study to calculate the cost effectiveness and feasibility in the field.

REFERENCES

[1] D.C. Montgomery, Design and analysis of experiments, John Wiley Sons Singapore Pte. Ltd, eighth edition, 2013

[2] S. A. Prathapar, M. Ahmed, S. Al Adawi and S. Al Sidiari, "Design , construction and evaluation of an ablution water treatment unit in Oman : a case study Design ," Int. J. Environ. Stud., vol. 63, no. 3, pp. 283–292, 2006.

[3] G. P. Winward, L. M. Avery, T. Stephenson, and B. Jefferson, "Chlorine disinfection of grey water for reuse : Effect of organics and particles," Water Research, vol. 42, pp. 483–491, 2008.

[4] S. S. Dalahmeh, M. Pell, B. Vinnerås, L. D. Hylander, I. Öborn, and H. Jönsson, "Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater," Water. Air. Soil Pollut., vol. 223, no. 7, pp. 3657–3671, 2012.

[5] C. Ramprasad and L. Philip, "Surfactants and personal care products removal in pilot scale horizontal and vertical flow constructed wetlands while treating greywater," Chem. Eng. J., vol. 284, pp. 458–468, 2016.

[6] S. Pushkar, S. Nusrat, A. Sabih, A. J. K. Singh, and M. Kumar, "A Study on Grey Water Treatment Processes : A Review," Int. J. Sci. Res. Dev., vol. 3, no. 8, pp. 413–416, 2015.

[7] P. Murthy P. M., S. Murthy B.M., and S. Kavya, "Commerce Engineering Greywater Treatment & Reuse : A Technological Review," Glob. J. Res. Anal., vol. 3, pp. 408– 410, 2016.

[8] D. Mandal, P. Labhasetwar, S. Dhone, A. S. Dubey, G. Shinde, and S. Wate, "Water conservation due to greywater treatment and reuse in urban setting with specific context to developing countries," Resour. Conserv. Recycl., vol. 55, no. 3, pp. 356–361, 2011.

[9] I. Kowalska, "Surfactant removal from water solutions by means of ultrafiltration and ion-exchange," Desalination, vol. 221, pp. 351–357, 2008.

[10] L. A. Ghunmi, G. Zeeman, M. Fayyad and J. B. Van Lier, "Technology Grey Water Treatment Systems : A Review," Crit. Rev. Environ. Sci. Technol., vol. 41, pp. 657–698, 2011.

[11] D. Mandal, P. Labhasetwar, S. Dhone, A. Shankar, G. Shinde, and S. Wate, "Water conservation due to greywater treatment and reuse in urban setting with specific context to developing countries," *Resour. Conserv. Recycl.*, vol. 55, pp. 356–361, 2011.

[12] S. S. Dalahmeh, M. Pell, and B. Vinnerås, "Efficiency of Bark , Activated Charcoal , Foam and Sand Filters in Reducing Pollutants from Greywater," *Water Air Soil Pollut*, Vol. 223, pp. 3657–3671, 2012.

[13] M. Pidou, L. Avery, T. Stephenson, P. Jeffrey, S. A. Parsons, S. Liu, F. A. Memon, and B. Jefferson, "Chemical solutions for greywater recycling," Chemosphere, vol. 71, no. 1, pp. 147–155, 2008.

[14] S. B. Parjane and M. G. Sane, "Performance of grey water treatment plant by economical way for Indian rural development," Int. J. ChemTech Res., vol. 3, no. 4, pp. 1808–1815, 2011.

[15] M. Sanchez, M. J. Rivero, and I. Ortiz, "Photocatalytic oxidation of grey water over titanium dioxide suspensions," Desalination, vol. 262, no. 1–3, pp. 141–146, 2010.

[16] R. Kim, S. Lee, J. Jeong, J. Lee, and Y. Kim, "Reuse of greywater and rainwater using fiber filter media and metal membrane," Desalination, vol. 202, pp. 326–332, 2007.

[17] G. Z. Ramon and M. Green, "Low strength graywater characterization and treatment by direct membrane filtration," Desalination, vol. 170, pp. 241–250, 2004.J. G. March, M. Gual, and F. Orozco, "Experiences on greywater re-use for toilet flushing in a hotel (Mallorca, Island, Spain)," Desalination, vol. 164, no. 3, pp. 241– 247, 2004.

[18] I. Soster-Turk S, Petrini and M. Simoniˇ, "Laundry wastewater treatment using coagulation and membrane filtration," Resour. Conserv. Recycl., vol. 44, pp. 185–196, 2005. N. Widiastuti, H. Wu, M. Ang, and D. Zhang, "The potential application of natural zeolite for greywater treatment," Desalination, vol. 218, no. 1–3, pp. 271–280, 2008.

[19] G. Antonopoulou, A. Kirkou, and A. S. Stasinakis, "Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods," Sci. Total Environ., vol. 455, pp. 426–432, 2013.

[20] K. Chaillou, C. Gérente, Y. Andrès, and D. Wolbert, "Bathroom Greywater Characterization and Potential Treatments for Reuse," Water Air Soil Pollut., vol. 215, no. 1, pp. 31-42, 2011.

[21] K. A. Vakil, M. K. Sharma, A. Bhatia, A. A. Kazmi, and S. Sarkar, "Characterization of greywater in an Indian middle-class household and investigation of physicochemical treatment using electrocoagulation," Sep. Purif. Technol., vol. 130, pp. 160–166, 2014.

[22] E. Eriksson, K. Auffarth, M. Henze, and A. Ledin, "Characteristics of grey wastewater,"Urban Water, vol. 4, pp. 85–104, 2002.

[23] B. S. Sahani and N. H. S. Ray, "Characterization and treatment of grey water using sequencing batch reactor," Int. J. Innov. Res. Stud., vol. 3, no. 5, pp. 481–499, 2014.

[24] I. Al baz, R. Otterpohl, and C. Wendland, "Efficient Management of Wastewater. Its Treatment and Reuse," Project funded by European Union, 2008.

[25] A. Gross, D. Kaplan, and K. Baker, "Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB)," Ecol. Eng., vol. 31, no. 2, pp. 107–114, 2007.

[26] R. Liu, X. Huang, L. Chen, X. Wen, and Y. Qian, "Operational performance of a submerged membrane bioreactor for reclamation of bath wastewater," Process Biochem., vol. 40, pp. 125–130, 2005.

[27] P. L. Paulo, C. Azevedo, L. Begosso, A. F. Galbiati, and M. A. Boncz, "Natural systems treating greywater and blackwater on-site: Integrating treatment, reuse and landscaping," Ecol. Eng., vol. 50, pp. 95–100, 2013.

[28] M. S. Fountoulakis, N. Markakis, I. Petousi, and T. Manios, "Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing," Sci. Total Environ., vol. 551–552, pp. 706–711, 2016.

[29] A. Gross, O. Shmueli, Z. Ronen, and E. Raveh, "Recycled vertical flow constructed wetland (RVFCW)-a novel method of recycling greywater for irrigation in small communities and households," Chemosphere, vol. 66, no. 5, pp. 916–923, 2007.