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Using Intermittent Sand Filters of Various Depths to Remove NH_3-N, NO_3N and NO_2N from the Wastewater of Sugar Milling Factory

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Abstract

Intermittent sand filter systems have been used in wastewater treatment according to Selecky (2012) especially their application for on-site wastewater management. Intermittent sand filters have not been used to treat effluent from sugar factories in Kenya. There is very limited information on how to optimize their application in treating effluent from sugar factory in Kenya. This study focused on optimization of intermittent sand filter used in treatment of wastewater from sugar factory. Samples of wastewater were randomly taken from Kibos Sugar and Allied factories. These samples were loaded into sand filters with different sand depths of 0.30, 0.45 and 0.60m. Different loading rates, volumes and frequencies were applied for each depth. Samples from the filtrate were collected and analyzed in the laboratory for NH_3-N, NO_3-N and NO_2-N values. The data was subjected to analysis of variance for fractional factorial (ANOVA) using the GenStat Version 13.2 computer programme. Wastewater generated from the sugar factories had NH_3-N, NO_3-N and NO_2-N were within the WHO acceptable limits. The sugar factory managers targeting to remove NO_3-N should use a sand filter with a depth of 0.45m by loading it at a rate of 2L/min, volume of 30L and frequency of 12hrs. To remove NO_2N using a sand filter of 0.45 m deep, they should use a loading rate of 4L/min, loading volume of 10L and loading frequency of 12hrs.

Keywords: Effluent, factory, filter, intermittent, sand, sugar, wastewater.

1. Introduction

Water is required in various activities which include industrial, agricultural and domestic functions. However water degrades in quality after use with various pollutants (Hochstrat et al., 2008). Water pollution is a health hazard causing sickness to humans (Radojevic & Bashkin, 1999; Manahan, 2000) and according to Horan (1991), the identification of major sources of pollutants is important. Saxena and Madan (2012) pointed out that wastewater from sugar mills has high amount of production load such as suspended solids, organic matters, press mud, air pollutants, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The sugarcane milling factories in Kenya generates huge volumes of wastewater during milling and processing of sugarcane to various products. On average a Sugar Milling Factory produces about 2.22 to 4.16m^3 of wastewater during the processing of one ton of sugar (Kenya Sugar Board, 2005). Disposal of this wastewater is a challenge to the factories because they must conform to national and international environmental guidelines **(**Ahmad, 2010). Sugar factories in developing countries face significant challenges with regard to wastewater treatment since they currently use the stabilization ponds, anaerobic systems and land application systems (Vonsperling, 1996). These treatment systems consume a lot of land that could otherwise be used for sugarcane production. The risk of water pollution can be reduced if wastewater is fully treated using a properly designed treatment system.

Intermittent sand filters are engineered systems designed to utilize natural processes involving sand, coarse aggregates, soils and the associated microbial assemblages to treat wastewater (Selecky, 2012). The term intermittent sand filter (ISF) is used to describe a variety of packed-bed filters of sand or other granular materials available in the market. According to Reed et al. (1995), intermittent sand filters have been considered as an efficient technology for wastewater treatment that has low construction and operation costs, low energy requirements and simple operation and maintenance. The type, size and location of ISF depend on the landscape, effluent composition, wastewater flow, performance, regulatory requirements and characteristics of the receiver site (Adams et al., 1998). The ISFs are designed based on under drain made of PVC liner or structure filled with sand placed in a drainage channel. Intermittent sand filters decompose or biodegrade wastewater constituents by bringing the wastewater into contact with a well developed aerobic biological community attached to the surfaces of the filter media

The basic components of ISFs include a dosing tank, pump and controls (or siphon), distribution network, and the filter bed with an under drain system. The wastewater is intermittently dosed from the dosing tank onto the filter through pipes. A network of distribution pipes is put on top of the filter to distribute the wastewater evenly on the filter medium while a pump is put to enable intermittent dosing. The dosage then percolates through the sand media to the under drain and is discharged. In the ISFs, pollutants are removed from the wastewater through a combination of physical, chemical and biological processes. These include sedimentation, precipitation, adsorption to sand particles and microbial digestion (Brix, 1993; Vymazal, 2005).

According to Selecky (2012), a lot of information on intermittent sand filter technology has been produced and used for on-site wastewater management. However, they have not been used to treat wastewater from sugar factories. The performance of ISF is influenced by variables such as media depth, particle size distribution, mineral composition of the media, wastewater pre-treatment, hydraulic and organic loading rates, temperature and dosing techniques (Tchobanoglous & Burton, 1991). The ISF treatment systems work well where wastewater reuse is desired, land is limiting and wastewater generators are concentrated.

2. Materials and Methods

The experimental site was set at Kenya Sugar Research Foundation (KESREF) in Kisumu County and the wastewater was collected from Kibos Sugar and Allied Industries Limited (KSAIL) located 5 km from KESREF Offices. The filters were sized based on dissolved oxygen (DO) using Streeter-Phelps Equation. The system experimental set up was composed of three filters with sand depths of 0.3, 0.45 and 0.60m. Each filter had a diameter of 0.60m. The filters were made from sand overlaid on gravel placed to a depth of 0.1m. The sand and gravel were graded using the standard mechanical sieve analysis method (ASTM 422-63). A formwork was made from timber to support the structure of the filter. The formwork was made with cider posts, timber and iron sheets for roofing. A wastewater holding tank of 500 L with a cover was placed on the rooftop. The 300L loading tanks and sand filters were placed in the roofed structure to shield them from direct sunshine, wind and rain. The PVC pipes and control valves of 50mm diameter were used in the plumbing works as shown in Figure 1. To allow the wastewater to load freely by gravity and to avoid loading sludge into the filter, a feeding line to each of the filter was fitted in the loading tank and extended mid way to the depth in the loading tanks. The loading tanks were graduated at 10L intervals from the highest level of the loading pipe and entry to the filter loading pipe marked zero.

Raw wastewater generated from the sugar factory was collected immediately and loaded to the overhead holding tank using a manually operated pump. The wastewater was released to the loading tanks through the PVC pipes and butterfly control valves. The wastewater was then delivered to the filter through another set of 50mm diameter PVC pipes fitted with control valves. The wastewater was finally distributed through perforated 32 mm diameter PVC pipes which had been drilled into a diameter of 5mm spaced at 50mm on the upper side of the distribution line. This was to reduce compaction by wastewater on the sand media and to ensure that the wastewater was distributed uniformly on the entire filter surface. To attain loading rates of 1, 2 and 4L/min in the filters, trial runs were done at a constant head and by regulating the opening of the control valves. The valves were marked after attaining the required flow rate. The system was calibrated using clean water. In addition, test runs were also done with wastewater during the testing stage. To attain the desired constant head after calibration, an overflow pipe was fitted to collect the excess flow and return it through pumping to the overhead tank.

The three sand filters of depths 0.3, 0.45 and 0.60m were each filled with gravel at depths of 0.1m. The sand was overlaid on the coarse aggregates for each depth. Three loading volumes of 10, 15 and 30L were loaded to each filter at rates of 1, 2 and 4L/min. In addition, the filters were subjected to three dosing frequencies once in 8, 12 and 24hrs. The filters received varying loads of contaminants based on the treatments. The raw wastewater had a retention time set at 2 days before loading to the filters. The lowest and highest loading volume of 10 and 90L respectively. This was obtained by the highest and the lowest combinations of treatment given by loading a volume of 30L with a frequency of once every 8hrs while the lowest loading was obtained by loading a volume of 10L with a frequency of once in 24hrs. The outlet flow volume was measured by counting the number of times a calibrated 10L-bucket was filled and emptied.

The inlet and outlet wastewater samples from the filters were collected as grab samples from 15th May to August 23rd 2012. The inlet samples were collected at the time of loading the filters. Outlets samples were taken from the collection buckets at the outlet of each filter. After completion of each run, each filter was loaded with 5L of wastewater for the survival of the micro-organisms before the next batch was loaded. Part of the samples was used to determine the pH, conductivity, dissolved oxygen and water temperature values in situ. The other portion of the sample was taken for laboratory analysis where the analyses were carried out. The $BOD_{5,}$ Ammonium (NH_4)-N, Nitrate (NO_3)-N and Nitrite (NO_2)-N were analyzed according to standard methods for water and wastewater analysis (APHA, 2005). In addition to these parameters, the TSS which is a measure of the filterable matter in the water sample (Kadlec et al., 2000) was also determined using the mass balance method (Eaton et al., 2005). The results were presented in a tabular form. To determine the critical depth, the results were analyzed based on the percentage removal of (NH_4^+)-N, (NO_3)-N and (NO_2)-N from all the treatment combinations of filter depth, loading rate, volume and frequency.

The filters were subjected to different hydraulic retention times at different depths. The filters were subjected to the three loading volumes which were loaded at three different rates and frequencies. Samples from each filter after each treatment were collected and analyzed in situ and then at the laboratory. The percentage removal of (NH_4^+)-N, (NO_3)-N and (NO_2)-N was determined and results recorded. The filters were subjected to various treatment combinations and data collected on wastewater quality and quantity. Each run in every filter represented a different combination of operational parameters. Samples from the filters were taken every 8hrs after the filters had been loaded.

The fractional factorial design was generated using the GenStat 13.2 software (Grant, 2010). This was used to analyze fractional factorial design output. The data was analyzed using Analysis of Variance (ANOVA) for Fractional Factorial Design or Analysis of an unbalanced design. In this study, treatment efficiency was defined as the ability of the filter to remove NH_3-N, NO_2N and NO_3N from the wastewater.

3. Results and Discussion

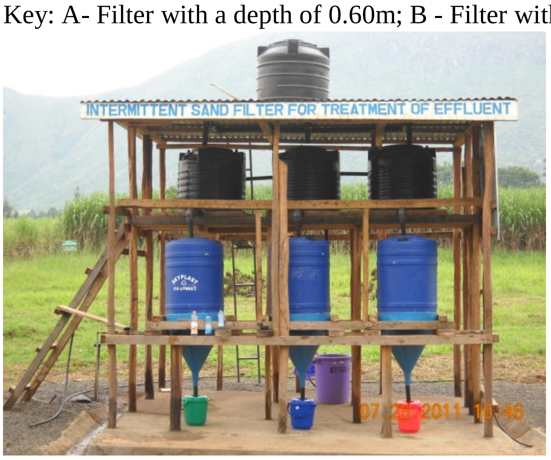
The results on the depth of the filters and removal of various pollutants that affect the quality of the wastewater generated from sugar factories are presented and the relationship between the loading rate, volume, frequency and sand filters of different depths. The results of the optimum combination of loading rate, loading volume and loading frequency on the performance of sand filter at different depths are also presented.

Table 1 presents the analyzed results of raw wastewater from Kibos sugar factory and the results of the three filters of varying depth and indicate mean values of each pollutant removed. The sand filter with a depth of 0.30m removed the highest amount of NH_3-N followed by a sand filter with a depth 0.45m. The sand filter with a depth of 0.45m recorded the highest removal of NO_3-N and NO_2-N at 2.96mg/l and 1.04mg/l with a mean of 1.57mg/l and 0.33mg/l respectively. The sand filter with a depth of 0.60m removed a maximum of 0.52mg/l of NH_3-N with a mean of 0.02mg/l.

Table 1: Initial Pollutants Load and Amount Removed by Each Filter

	NH_3-N	NO_3N	NO_2N	NH_3-N			NO_3-N			NO_2-N		
Run	Raw wastewater Concentration. (mg/l)			A	B	C	A	B	C	A	B	C
1	0.45	1.16	0.13	0	0	0.33	0	0.73	1.03	0.097	0.113	0.092
2	0.16	0.56	0.15	0	0	0	0.44	0.50	0.46	0.109	0.117	0.091
3	0.39	1.18	0.10	0	0	0.38	1.09	1.11	1.08	0.033	0.070	0.083
4	0.71	0.40	0.07	0.52	0.40	0.45	0.32	0.34	0.24	0.027	0.015	0.035
5	0.61	3.28	0.20	0.20	0.22	0.13	2.48	2.49	2.68	0.038	0.139	0.175
6	0.58	3.69	0.48	o.12	0.30	0.40	1.73	2.96	1.03	0.073	0.124	0.276
7	0.59	2.64	1.23	0.13	0.26	0.30	0.10	2.39	2.16	0.669	1.035	0.619
8	0.05	1.46	0.24	0	0	0.04	0.31	0.95	0.97	0.128	0.226	0.223
9	0.31	2.78	1.16	0.16	0.18	0.27	0.01	2.60	1.79	0.888	0.856	0.947
Std.dev	0.222	1.211	0.45	0.167	0.156	0.163	0.872	1.03	0.792	0.318	0.373	0.305
Max	0.71	3.69	1.23	0.52	0.40	0.45	2.48	2.96	2.68	0.888	1.04	0.947
Min.	0.05	0.40	0.07	0	0	0.33	0	0.34	0.24	0.027	0.015	0.035

Key: A- Filter with a depth of 0.60m; B - Filter with a depth of 0.45m; C - Filter with a depth 0.30m



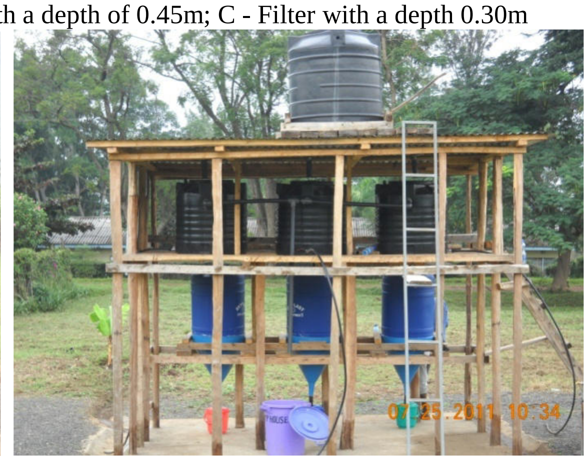


Figure 1: Front and back views of the experimental setup showing overflow and drain pipes

Table 2 presents the results of the three filters of varying depth and indicate mean values of each pollutant removed. The results indicate that there was a statistical significant difference between the means of pollutant removed and filters of different sand depth at p=0.05.

Table 2: Comparison of the means and p-values for t-test statistics of pollutant removal by filters of different sand depths

Variate	Mean	S.e.d	t-test statistics	p-value
NH_3N	0.4278	-	-	-
A	0.3022	0.0915	1.37	0.189
B	0.2767	0.0865	1.75	0.100
C	0.1722	0.0899	2.84	0.012*
NO_2N	0.4178	-	-	-
A	0.1887	0.165	1.39	0.193
B	0.1183	0.159	1.89	0.090
C	0.1354	0.166	1.71	0.117
NO_3N	1.906	-	-	-
A	1.186	0.532	1.35	0.195
B	0.342	0.415	3.77	0.005*
C	1.650	0.570	0.45	0.660

Key *- There was statistical significant difference between the means of the variate and the treatments at p=0.05 S.e.d-standard error difference

Figure 2 presents the results of sand filters of three varying depths and the amount of pollutants each removed from the effluent in percentages. The sand filter with a depth of 0.45m removed the highest amount of NO_3-N at 87% while the sand filter with a depth of 0.30m removed the highest amount of NH_3-N and NO_2-N at 75% and 77% respectively.

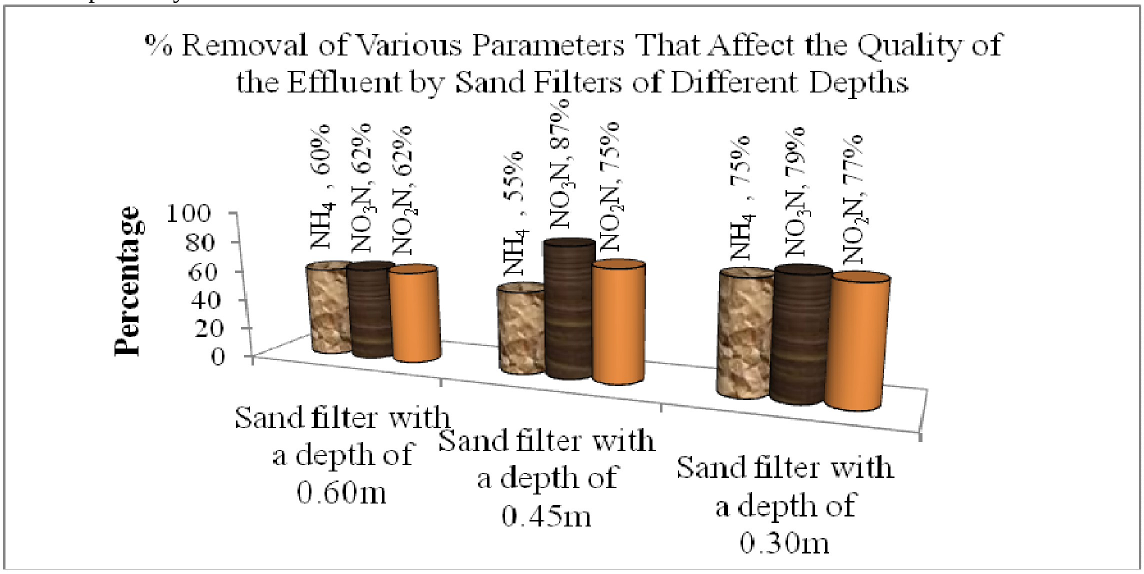


Figure 2: Sand filters of three depths and the percentage of pollutants each removed from the wastewater.

Table 3 presents the results of pollutants removed by different sand filters at different loading Rate, Frequency and Volume for example a filter with sand depth of 0.60m removed 47% when loaded at 2 L/min, 46% when loaded with 30L and 56% at a loading frequency once every 12hr. The same filter removed NO_3N at 68% when loaded at 2 L/min, 59% loaded with 30L and 75% at a loading frequency of 8hrs. It also removed 54% when loaded at 2 L/min NO_2N, 54% when loaded with 30L and 68% at a loading frequency of 12hr. The same analogy was used to analyse the removal rate of NO_3N and NO_2N respectively.

The LSD value for NO_3N was 0.50 for all the three filter depth while the S.E at 95% was 0.25. The LSD value for NO_3N was 0.13 for all the three filters of different depths while the S.E at 95% was 0.26. The results indicated that there was a statistical significant difference between the means of amount of ammonia removed and the filter depths at (p=0.001). Similarly the results showed a statistical significant difference between the means of the amount of NO_3N removed and the three filter depths at p=0.05. However there was no statistical significant difference between the means of amount of NO_3N removed and the three loading volumes, frequency and rates at p=0.05. Similarly there was no statistical significant difference between the removal of NO_2N by the three filter depths and the three loading rates at p=0.05.

Table 3: Pollutants Removed by different Sand Filters at different loading Rate, Frequency and Volume

	% removal at different treatment levels									S.E at 95%	LSD (at 5.0%) for predicted means
	Loading rate (L/min)			Loading volume (L)			Loading frequency (hr)				
	1	**2**	**4**	**10**	**15**	**30**	**24**	**12**	**8**		
NH_3-N removal at 0.60m	31	47	30	23	32	46	26	56	41		
NH_3-N removal at 0.45m	55	50	48	54	47	47	45	44	42	0.11	0.22
NH_3-N removal at0.30m	24	73	78	58	72	58	79	48	60		
NO_3N removal at 0.60m	57	68	52	60	58	59	55	44	75		
NO_3N removal at 0.45m	89	74	82	87	77	79	58	83	63	0.25	0.50
NO_3N removal at 0.30m	82	57	82	77	76	71	80	65	69		
NO_2N removal at 0.60m	50	54	39	41	48	54	21	68	54		
NO_2N removal at 0.45m	63	59	74	64	80	78	48	55	49	0.13	0.26
NO_2N removal at 0.30m	67	64	76	61	66	68	69	52	76		

Key: S.E –standard Error; LSD- Least Significant Difference

Table 4 presents the P-values derived from ANOVA results comparing the pollutants removed by different sand filters at different loading rate, volume and frequency. The values with * indicate statistical significant difference on the parameter removed with the treatment applied to the sand filters.

Table 4: P-values derived from ANOVA results comparing the pollutants removed by different Sand Filters at different loading Rate, Frequency and Volume

Pollutants	Treatment				Interaction		
	Filter depth	Volume	Freq	Rate	Filter and Frequency	Filter and Volume	Filter and rate
NH_3-N	0.001*	0.002*	0.280	0.284	0.267	<.001*	0.360
NO_3-N	<.001*	0.829	0.039*	0.340	<.001*	<.001*	<.001*
NO_2-N	0.653	<.001*	0.006*	0.661	0.705	0.041*	0.004*

Key *-There was statistical significant difference between the means of the variate and treatments at p=0.05

The sand filter with a depth of 0.45m removed the highest amount of NO_3N at 75% when the combination of loading rate, loading volume and loading frequency was 2L/min, 10L and 8hrs respectively. Analysis of the other two pollutants was done in the same manner. The treatment combination of loading rate, volume and frequency had a significant effect on how each of the filter performed thence from the results, each filter had it unique optimum combination of operating conditions as shown in Table 5.

Table 5: Performance of the Sand Filters in Removing Pollutants

FD	Parameter	**LR1**	**LR2**	**LR3**	**LV1**	**LV2**	**LV3**	**LF1**	**LF2**	**LF3**
0.60m	NH_3-N	31	47	30	23	32	46	26	56	41
	NO_3N	57	68	52	60	58	59	55	44	75
	NO_2N	50	54	39	41	48	54	21	68	54
0.45m	NH_3-N	55	50	48	54	47	47	45	44	42
	NO_3N	89	74	82	87	77	79	58	83	63
	NO_2N	63	59	74	64	80	78	48	55	49
0.30m	NH_3-N	24	73	78	58	72	58	79	48	60
	NO_3N	82	57	82	77	76	71	80	65	69
	NO_2N	67	64	76	61	66	68	69	52	76

Key: FD- Filter depth; LR1, LR2 and LR3 represent loading rates of 1, 2 and 4L/min; LV1, LV2 and LV3 represent Loading volumes of 10, 15, and 30L; LF1, LF2 and LF3 represent Loading frequencies of 24, 12 and 8hrs.

The study found that a 0.45m deep sand filter achieved the highest removal efficiency of most pollutants. It removed above 87% of pollutants in sugar factory wastewater when loaded at 2L/min., 10L and a frequency of 12hours except the ammonium which was removed by a sand filter with a depth of 0.3m (Table 6). These results indicated that complete removal of all pollutants could be achieved if the wastewater was to be passed through a second filter in series.

Table 6: Optimum combination of Operational Parameters from Different Filter depths

Pollutant	Filter Depth(m)	Loading Rate (L/min.)	Loading Volume (L)	Loading Frequency (Hrs.)	Pollutant removal (%)
NO_3-N	0.60	1	15	12	86
NO_2-N	0.60	1	30	8	62
NH_3-N	0.60	1	30	12	62
NO_3-N	0.45	2	10	12	87
NO_2-N	0.45	4	10	12	80
NH_3-N	0.45	1	10	12	55
NO_3-N	0.30	2	10	12	79
NO_2-N	0.30	4	10	12	77
NH_3-N	0.30	4	15	24	75

4. Conclusions and Recommendations

The sand filter with a depth of 0.45m removed an average of 0.06mg/l of NH_3N, 1.57mg/l of NO_3N and 0.33mg/l of NO_2N. It was concluded that the critical depth of intermittent sand filter to remove the three pollutants in sugar factory wastewater was 0.45m.

The sand filter with a depth of 0.45m removed the highest amount of NO_3N and NO_2N from the factory wastewater compared to that of 0.30m and 0.60m at varying loading rate, loading volume and loading frequency. However, the filter with a depth of 0.30m sand removed the highest amount of NH_3-H at different loading rate, volume and frequency. A statistical significant difference between the amount of ammonia and NO_3N removed and the filter depths at p=0.05 was observed. Further no statistical significant difference between the amount of NO_3N removed and loading volumes, frequency and rates or between the removal of NO_2N by the filter depths and loading rates at p=0.05.

It was concluded that each sand filter had its unique combination of loading rate, volume and frequency. A sand filter with a depth of 0.60m performed optimally when loaded at 1l/min. with15L of wastewater at a frequency of 12hours. The other two filters had their optimum combination.

It was concluded that a filter with a depth of 0.45m removed over 87% of most pollutants when loaded at 2L/min., 10L and a frequency of once every 12 hours. To remove NO_2N using a sand filter of 0.45m deep, the sugar factory managers should use a loading rate of 4L/min, loading volume of 10L and loading frequency of 12 hours.

4.1 Recommendations

The researcher recommend more research work on re-aeration cycle of the sand filter after the use of the dissolved oxygen by the percolating wastewater and also replication of this research for a longer period with more sand filters with other types of effluent

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References

Adams, A., T. H. Micheal, B. Arrington, and G. Young. (1998). Failure Analysis Chart for Troubleshooting Septic System*s* Journal, Vol. 14 Iss: 2, pp.220 – 240.Ahmad, R. (2010). Global Sanitation Fund Water Supply & Sanitation Collaborative Council: Sanitation sector analysis report Pakistan.

Ahmad, A. (2010). Adsorption of methylene blue on low-cost adsorbents: A Phd. Thesis pp 55-60.

American Public Health Association. (2005).Onsite Wastewater Treatment Systems: Technology Fact Sheet 10; Intermittent Sand/Media Filters.

Brix, H. (1993). Wastewater treatment in constructed wetlands: system design, removal processes, and treatment performance.

Grant, B. S. (2010). Analysis of fractional Design using Genstat software : *Science and Technology* (10): Vol. 333 no. 6020 pp. 450-459.

Hochstrat, R., Wintgens, T. Melin, and P. J. Jeffrey. (2008). Towards a European water recycling policy. Journal of environment, 39: pp 45 – 50.

Horan, N. J. (1991). Biological wastewater treatment systems. Theory and operations. John Wiley and sons ltd. New York.

K. S. B. (2005). Effluent treatment and discharge to natural waters-Sugar factory report.

Manahan, S. E. (2000). Practical environmental analysis. The royal society of chemistry. Cambridge. UK.

Radojevic, M., and V. N. Bashkin. (1999). Practical environmental analysis. The royal society of chemistry. Cambridge. UK.

Reed, S. C., R. W. Crites and J. E. Middlebrooks. (1995). Natural Systems for Waste Management and Treatment, 2nd ed. McGraw-Hill, USA.

Saxena, C and. S Madan. (2012). Evaluation of adsorbents efficacy for the removal of pollutants from sugar mill effluent. ARPN Journal of Agricultural and Biological Science VOL. 7, NO. 5, 2012 ISSN 1990-6145.

Selecky, M. (2012). Recommended Standards and Guidance for Performance, Application, Design, and Operation and Maintenance Intermittent Sand Filter Systems. Washington state department of health. Division of environmental health of the shelfish and water protection. Retrieved 9th April from www.doh.wa.gov/…ortals/1/Documents/Pubs/337-007.

Tchobanoglous, G., and F. L. Burton. (1991). Wastewater Engineering: Treatment, Disposal, Reuse, Metcalf and Eddy.

von Felde, K., and S. Kurnst. (1997). N- and COD-removal in vertical-flow systems. Water Science and Technology 35(5): 79-85.

Vonsperling, M. (1996). Comparison among the most frequently used systems for wastewater treatment in developing countries. Water Science Technology. 33: pp 59–72.

Vymazal, J. (2005). Horizontal sub-surface flow and hybrid constructed systems for wastewater treatment. *Ecological Engineering* 25: 478-490