Onsite Greywater Treatment using Pilot Scale "GROW" Technology

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ABSTRACT

The GROW Technology for greywater treatment was installed at the MUET (Mehran University of Engineering & Technology), hostel and run under continuous flow conditions with hydraulic loading rate of 0.15md^{-1}. The monitoring and analysis of influent and effluent water were carried out during January-December, 2010. Local plants species such as water hyacinth, Pennywort (duck weed), Mint and Cattail were used in the GROW rig as a mixed mode. Coarse Gravels were filled in the troughs as a medium. The collected samples were analyzed for BOD_5 (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), pH, and DO (Dissolved Oxygen). Removal efficiencies of BOD_5, COD and TSS were calculated as 83.0, 69.0 and 84.0% respectively. DO was found increased from 0.6-3.5 mg.dm^{-3} while pH was observed between 6.5-7.8.

Key Words: **GROW Technology, Greywater, Biochemical Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solids, Dissolved Oxygen.**

1. INTRODUCTION

Grey water is defined as wastewater without any input from toilets, which corresponds to wastewater produced in bathtubs, showers, hand basins and laundry machines in households, office buildings, schools, etc. [1-3].The total grey water fraction has been estimated to account for about 75% of all wastewater of the combined residential sewage [4].The characteristics of grey water vary regionally and over time [5]. Three factors significantly affect grey water compositions: water supply quality, the composition of the system that transports both grey and drinking water and the activities in the house [6]. The greywater tends to more lightly polluted than black water, particularly in terms of suspended solids and pathogens[7]and therefore, should require less expensive treatment prior to reuse. Possibilities of reuse for this fraction of wastewater have come into special focus. Approximately one-third of domestic water consumption is used for bathing, showering and hand washing; and further third tends to be used for toilet flushing [8].Dixon, [9] revealed that storage of greywater can improve water quality through settling of suspended solids and aerobic microbial growth in sedimentation tank. Treated grey water can be reused for many activities such as toilet flushing, garden watering and recreational irrigation of gardens, golf

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courses, vehicle washing, fire protection, steam generation, aquifer recharging etc. [10].Usually simple treatment system for the purpose of landscape irrigation, like sand/gravel filtration or settlement and flotation are operated to prevent clogging of the distributing system. A more sophisticated design is needed, if the treated water is used "in-house", e.g. for toilet flushing.

Constructed wetlands are artificial wastewater treatment systems consisting of shallow (less than 1m deep) ponds or channels which have been planted with aquatic plants. The system relies upon aerobic bacteria, biological, physical and chemical processes to treat greywater/wastewater [11]. The GROW System, based on constructed wetland technology, is essentially a garden of aesthetically pleasing aquatic or marginal plants growing within a series of shallow troughs.

1.1 Green Roof Water Recycling System

The GROW system was the patent of Chris Shirley-Smith, who is Director, Water Works UK, is collaborating in research with Imperial College London and Cranfield University. The "GROW System" uses semi-aquatic plants to treat grey water, which can then be reused for activities such as flushing the toilet, home gardening etc.

Using GROW System, much of the water that enters a building can be used twice before being placed into the national wastewater management system.

GROW is designed for multi-occupancy buildings so there is a continual supply of greywater and the plants do not dry out. A typical five-trough system would process 1m^{3}of water a day which is enough green water for 25-40 people.

2. MATERIALS AND METHOD

2.1 Greywater Collection

The greywater generated from the Mehran University Teachers Hostel was treated through the GROW technology, a natural low cost method of treatment. Total fifty residents of hostel were residing at ground and first floor in one (right) wing. This was considered as proper size for the present study.In this study total ten bath rooms, ten sinks(wash basins)and floor washing area drain points were specially plumbed with plastic pipes(12.69 mm dia.) and connected to the greywater storage tank which was made of concrete having size of 2.13x1.52x1.21m (3.92m^3) constructed below the ground level. The water from bath rooms, hand wash basins, washing area and floor wash was collected in the storage tank by gravity and then pumped (1.0 H.P pump) to the feeding tank, (1.135m^3 capacity) daily two times at morning and evening at 09.00am and 06.00pm respectively, in order to continuous supply of greywater to the GROW rig. The feeding tank was placed on a concrete basement, above (0.6096 m) from the GROW rig. In case of excess volume of raw greywater in the storage tank it was drained out via drain outlet valve,provided at the bottom of the reservoir. The empty storage tank was ready to store fresh greywater. The reservoir was flushed and cleaned on weekly basis in order to remove settled solids and scum.

2.2 GROW System Installation

GROW System was established at the Teacher's Hostel, MUET (Mehran University of Engineering & Technology), Jamshoro, Pakistan. The "GROW" rig comprised five rows of two troughs connected in series and placed on tiered wooden frame work to representing a sloping roof. The first trough was approximately 1.5m above the ground and lowest (5th trough) was 0.5m above the ground. There were two baffles made of polyacrilic plastic of 10.0mm thickness, inserted in each row in order to maintain upward and down ward flow within the troughs. Two weirs at the head and tail of each row were provided in order to force and maintain the flow of incoming greywater through the gravel media. All five rows (troughs) were placed on a wooden frame in such a way as the first row was above the second one. The local plants species were placed in a separate plastic buckets (surrounded with small holes) dully filled with gravels and put in each row troughs. The density of plantation was 6-7 plants in each row with a distance of 0.305-0.457m between each. After that all the troughs were filled with coarse gravels of sized 20mm up to depth of 254mm. The medium (gravels) porosity was measured as 0.5. The height of first row and last row of "GROW" rig was 1.524 and 0.609m respectively above the ground level. Raw greywater was introduced into the head weir of the first row of GROW rig through a control valve provided at the bottom of feeding tank (inlet line). Gravity flow was maintained. The first row was kept without any plants so that it can act as a filter to allow settling down of suspended solids in the influent stream. The remaining four rows were planted with water hyacinth, pennywort (duckweed), mint and cattail (typha). The grey water was run through this mixed plantation regime for the biological treatment in open atmospheric conditions. The plug flow conditions were maintained within each row, containing gravel bed as a substrate. At the end of last row the treated water was finally collected as a"Green water", shown in Fig. 1. The zigzag flow pattern reduce the area required for the GROW rig.

2.2.1 Operating Conditions

The influent greywater flow was optimized and maintained in all experiments throughout as $0.720 m^3.d^{-1}$. The average organic loading rate applied to the system was $14.6 gBODm^{-2}.d^{-1}$ and $24.9 gCODm^{-2}.d^{-1}$. Other conditions and the plants used for this study are given in Table 1.

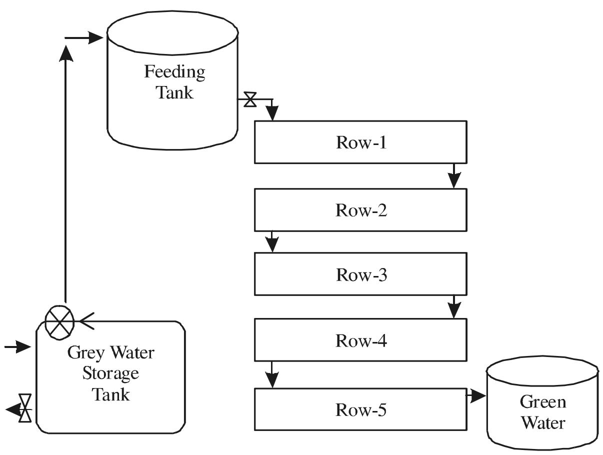

FIG.1. SCHAMATIC DIAGRAM OF THE GROW SYSTEM INSTALLED AT MUET, JAMSHORO

TABLE 1. OPERATING CONDITIONS FOR GROW SYSTEM.

Rows	1	2	3	4	5
Medium	Gravels				
Pattern of Plants	No Plant	Mixed Plantation Regime			
No of Plants	No Plant	6-7 Plants in each Row			
Name of Plants	No Plant	1. Water hyacinth (Eichhorniacrassipes) 2. Mint (Menthalongifolia) 3. Pennywort (Duckweed) 4.Cattail (Typhalatifolia)			
Flow rate	$0.720 m^3.d^{-1}$				
HRT	One Day				
Mode of Flow	Continuous Plug Flow (subsurface)				
Temperature, (Influent)	Summer 25-35 ± 2.0°C Winter 10-15°C				
Temperature, (Effluent)	Summer 22 - 32±1.0°C Winter 8-11°C				

The GROW system was run at ambient conditions and treatment data was collected for one year period from January-December 2010.

2.3 Samples Collection

The GROW system was run continuously (24hours/7days) with raw grey water in order to achieve acclimatization of the system and development of biofilm growth on the surface of medium. Weekly grab sampling procedure was carried out from the inlet and outlet locations of GROW rig between 12.00-1.00 pm. The samples were collected in disposable plastic bottles which were thoroughly cleaned with detergent and rinsed with distilled water prior to sampling. After getting the samples these were immediately send to the laboratory for the analysis.

2.4 Analytical Methods

The influent and effluent samples were analyzed for pH, DO, TSS, BOD_5 and COD. Analyses were carried out according to Standard Methods Examination of Water and Wastewater APHA [12] in the NCEAC (National Center of Excellence in Analytical Chemistry), University of Sindh, and Institute of Environmental Engineering & Management, Mehran University of Engineering & Technology, Jamshoro, Pakistan, laboratories. The samples were stored in refrigerator, maintained at 4°C.

3. RESULTS AND DISCUSSION

3.1 Raw Greywater (Influent)

The characteristics of household greywater can vary depending on the source, number of residents, their age, health status, life style, tap water source, water usage pattern and personnel use items (like soap, shampoo, detergents, mouthwash, toothpaste, hair dyes, shaving creams and body oils etc.).

The influent quality of greywater during the study period was found from medium to high strength in terms of organic compounds. The mean value of BOD_5 was calculated to be 115.0±33.5 $mg.dm^{-3}$ with minimum and maximum values of 79.0 and 170.0$mg.dm^{-3}$ respectively, as given in Table 2. These values were within 90-360 $mg.dm^{-3}$ range, as reported by Erikson, et. al.[6].

The mean COD was 228.0$mg.dm^{-3}$with minimum and maximum values of 132.0 and 280.0 $mg.dm^{-3}$ respectively as shown in Table 2. This was also comparable with 40-371 mg.dm^{-3}as found by Jefferson, et. al. [7]. The maximum concentration of 280.00 mg.dm^{-3} was observed during the water shortage period, from May-July 2010. The lower values 132.0 mg.dm^{-3} was found because of the more showering or uncontrolled use of fresh (potable) water or less no of residents during week end vacations at hostel.

The mean TSS was 118.0 mg.dm^{-3} with minimum and maximum values were 97.0 and 180.0 mg.dm^{-3} respectively. The mean influent quality parameters with standard deviation are given in Table 2.The resident's activities at hostel were observed throughout the study period and found that the maximum generation of greywater was in the morning and evening due to bathing, brushing, face washing and floor washing while some cloth washing was also observed which strongly affects greywater quality in terms of organic and inorganic load. Floor washing was also contributing to increase TSS. Since the storage tank was open to sky hence winds also contributing to increase TSS. The birds were also causing an additional source of organics in to the greywater.

In literature the BOD_5 of raw greywater ranged from 33-300 mg.dm^{-3}. The COD: BOD_5 ratio of influent greywater was 1.98:1, which was similar to1.69:1, Almoayied, et.al. [14] and lower as compared to 4:1 as reported by Jefferson, et. al. [15]. The ratio indicates higher biodegradability and less concentration of non-biodegradable compounds. While higher the ratio, decreases the bio decomposition of pollutants and corresponding deficiency in macronutrients such as nitrogen and phosphorus. In this study the average greywater generation rate was estimated as 54.0 L/c/d which is lower than 77.0 L/c/d as found in Cranfield University, UK [16]. This was, however, 59.0 L/c/d to the study conducted in Amman by Jefferson, et. al. [15]. The characteristics of greywater were found similar with other studies, as compared in Table 2.

TABLE 2. COMPARISON OF GREYWATER CHARACTERISTICS WITH DIFFERENT STUDIES AVAILABLE IN LITERATURE

Parameter	This Study	Pathan, et.al. [22]	Eriksson, et. al. [6]	Hernandez Leal, et. al. [23]	Jefferson, et. al. [13]	Dinox et. al. [9]
BOD5 (mg/l)	115±33.5 (79-170)	55.61±17.28 (36-77)	90-360	215±102	146±(54.3)	121
COD (mg/l)	228±75.6 (132-280)	146.05±49.08 (79-195)	13–550	425±107	451±(289)	371
TSS (mg/l)	118±25.6	154.63±45.25	-	-	100±(145)	-
pH	7.3±0.3	6.23±0.05-6.75±0.16	-	7-8	7.47±(0.29)	
DO	0.68±0.12	-	-	8.9 mg/L		3.5-5.2
COD: BOD	1.98	2.6	1.52	1.97	3.08	3.0

3.2 Performance of GROW System

The influent and effluent quality of greywater through GROW system was monitored for one year period from January-December 2010 and evaluated in terms of BOD_5, COD and TSS concentration. The average removal percentages of BOD_5 was 83.0%, as shown in Fig. 2. COD was 69.0% as shown in Fig. 3 and TSS was 84.0%as shown in Fig. 4.

The averaged dissolved oxygen concentration in raw greywater was found 0.68 mg.dm^{-3} and gradually increased up to maximum 2.1 mg.dm^{-3} in effluent stream as shown in Fig. 5 which confirms the aerobic treatment inside the system.

The maximum removal efficiency of effluent BOD_5 wasup to 96.7% during the summer season with mean value of 5.4 mg.dm^{-3} as compared with influent value of 160.0 mg.dm^{-3} and minimum removal efficiency was found in winter season as 72.5% with a mean value of 28.0 mg.dm^{-3} in comparison with influent value 102.0 mg.dm^{-3} as shown in Fig. 6.

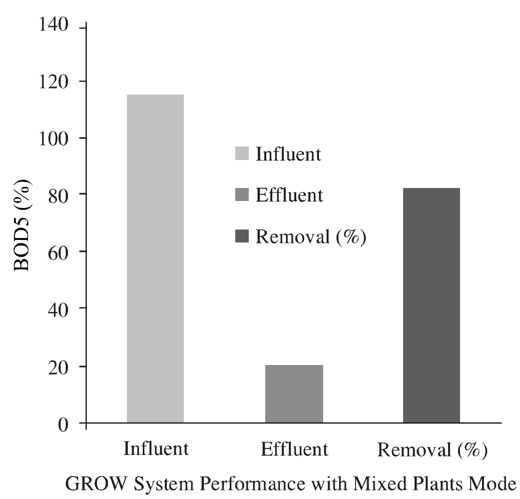

FIG. 2. INFLUENT AND EFFLUENT QUALITY IN TERMS OF BOD_5 REMOVAL PERCENTAGE

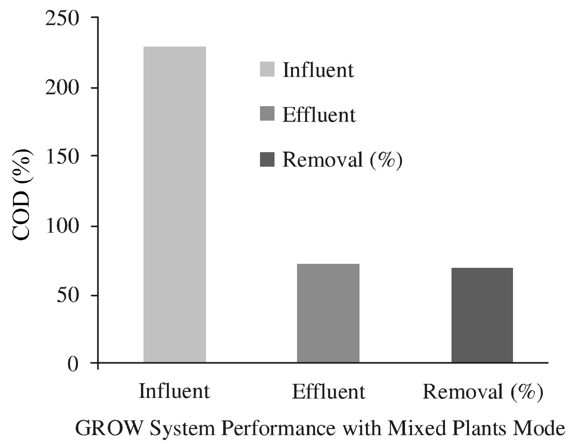

FIG. 3. INFLUENT AND EFFLUENT QUALITY IN TERMS OF COD REMOVAL PERCENTAGE

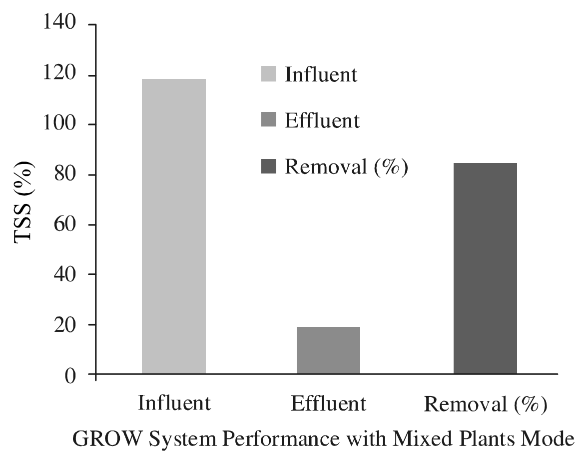

FIG. 4. INFLUENT AND EFFLUENT QUALITY IN TERMS OF TSS REMOVAL PERCENTAGE

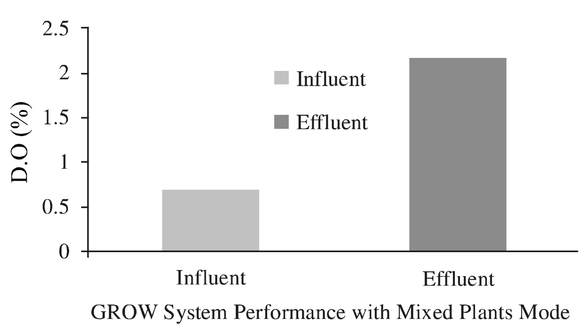

FIG. 5. INFLUENT AND EFFLUENT QUALITY IN TERMS OF DO

The maximum removal efficiency of effluent COD was up to 91.7% during the summer season with mean value of 18.0 $mg.dm^{-3}$as compared with influent value of 280.0 $mg.dm^{-3}$ and minimum removal efficiency was found in winter season as 64.0%with a mean value of 70.0 $mg.dm^{-3}$in comparison with influent value 194.0 $mg.dm^{-3}$ as shown in Fig. 6.

The maximum removal efficiency of effluent TSS was up to 94.8% during the summer season with mean value of 7.0 $mg.dm^{-3}$ as compared with influent value of 136.0 $mg.dm^{-3}$ and minimum removal efficiency was found in winter season as 73.4% with a mean value of 30.0 $mg.dm^{-3}$ in comparison with influent value 113.5 $mg.dm^{-3}$ as shown in Fig. 6.

This was observed during the study period that the system efficiency decreased as influent concentration was increased beyond upper limits values of BOD_5 and COD as 115 and 280 respectively as mentioned in Table 3. This is also important to note that 20-22% of BOD_5 was removed in the first row of GROW system, (filled with gravels only) throughout the study. Subsequently, the GROW system performance was found increasing with the growth of plants.

The average temperature of influent and effluent greywater during the summer and winter seasons ranged from 25-35±2.0 to 22-32±1.0°C and 10-15 to 8-11°C respectively as shown in Table 1.

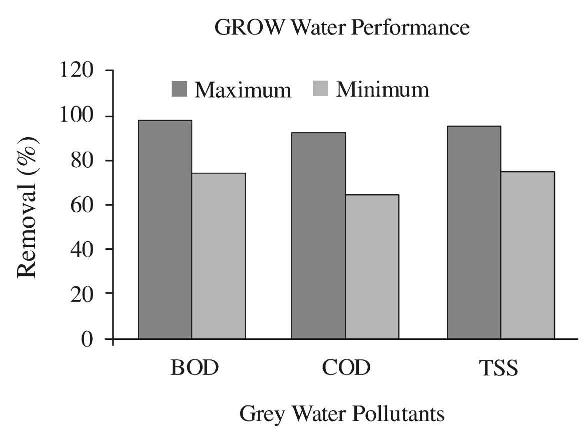

FIG. 6. GROW SYSTEM PERFORMANCE WITH MAXIMUM AND MINIMUM REMOVAL (%)

TABLE 3.THE EFFLUENT VERSES INFLUENT IN TERMS OF REMOVAL PERCENTAGE FROM GROW SYSTEM

Parameter	Average Influent	Average Effluent	Removal (%)
BOD_5 ($mg.dm^{-3}$)	115±33.5	20.0±3.2	83.0
COD ($mg.dm^{-3}$)	228±75.6	71.9±10.5	69.0
TSS ($mg.dm^{-3}$)	118±25.6	18.3±2.5	84.0
DO ($mg.dm^{-3}$)	0.67±0.02	2.1±0.65	66.0 increased
pH	7.3±0.3	7.8±0.5	-

4. CONCLUSION

The present study demonstrates that the onsite treatment of greywater, generated at Mehran University Hostel from bath rooms, wash basins, cloth washing activities (partially) and floor washing etc, through GROW System. Based on the findings of this study, The GROW System could be considered as a viable alternative to conventional treatment plants in urban areas. The benefits found are easily installed, easy to operate and less maintenance. This will ultimately decrease the load on fresh water demand and consequently less volume of domestic wastewater generation in highly dense urban areas. The green plantation of GROW system also effect on horticultural and aesthetic environment.

The performance of GROW system installed at Mehran University Hostel, found that overall pollutant removal efficiency was better than the similar system was investigated at Cranfield University UK in terms of TSS, BOD_5 and COD removal. The effect of temperature during summer season was also found significant as removal efficiency raised up to 96 and 91% for BOD_5 and COD respectively.

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REFERENCES

[1] Nolde, E., "Grey Water Reuse Systems for Toilets Flushing in Multi-Story Building - Over Ten Years Experience in Berlin", Urban Water, Volume 4,pp. 275-284, Germany, 2000.

[2] Nolde, E., "Greywater Reuse Systems for Toilet Flushing In Multi-Story Buildings - Over Ten Years' Experience in Berlin",Urban Water, Volume 1,pp. 275–284,Germany, 1999.

[3] Al-Jayyousi, Odeh, R., "Grey Water Reuse: Towards Sustainable Water Management", Desalination, Volume 156,pp. 181-192,Jordan, 2003.

[4] Dixon, A., Butler,D., and Fewkes, A., "Water Saving Potential of Domestic Water Reuse Systems using Greywater and Rainwater In Combination", Water Science &Technology, Volume 39,pp.25-32,UK, 1999.

[5] Christova-Boal, D., Eden, R.E., and McFarlane, S.,"An Investigation into Grey Water Reuse for Urban Residential Properties", Desalination, Volume 106,pp.391-397,South Africa,1996.

[6] Erikson, E., Auffarth, K., Mogens, H., and Ledin, A., "Characteristics of Grey Wastewater", Urban Water, Volume 4,pp. 85-104, 2002.

[7] Jefferson, B., Lain,A., Judd,J., andStephenson,T.,"Membrane Bioreactors and Their Role in Wastewater Reuse", Water Science &Technology, Volume 41,pp.97-204, 2000.

[8] Okun, D.A., "Distributing Reclaimed Water Through Dual System", American Water Works Association Journal, Volumel89, pp.153-160, 1997.

[9] Dixon, A., Butler, D., and Fewkes, A., "Influence of Scale in Grey Water Reuse Systems",Proceedings of AWWA/WEF Water Reuse,Conference, San Antonio, USA, January, 2000.

[10] Santala,E.,Uotila,J.,Zaitsev,G.,Alasiurua,R.,Tikka,R.,and Tnegvall,J.,"Microbiological Greywater Treatment and Recycling in An Apartment Building", Advanced Wastewater Treatment, Recycling and Reuse:Milan,pp.319-324, 2000.

[11] Akratos, C.S., and Tsihrintzis. V.A., "Effect of Temperature,HRT,Vegetation And Porous Media on Removal Efficiency of Pilot-Scale HorizontalSubsurface Flow Constructed Wetlands", Ecological Engineering, Volume 29,pp.173-191, 2007.

[12] APHA (American Public Health Association), "Standard Methods for Examination of Water and Wastewater", Washington DC, USA, 2005.

[13] Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R., and Judd, S., "Greywater Characterization and its Impacts on the Selection and Operation of Technologies for Urban Reuse", Water Science &Technology Volume 50, pp.157-164, 2004.

[14] Almoayied, K., Assayed, Sahar S., Dalahmeh, Wael, T, and Suleiman, "Onsite Greywater Treatment Using Septic Tank Followed by Intermittent Sand Filter: A Case Study of Abu Al-Farth Village in Jordan" ,International Journal of Chemical and Environmental Engineering,Volume 1, No. 1, July, 2010.

[15] Jefferson, B., Judd, S., and Diaper, C., "Treatment Methods For Grey Water",Decentralized Sanitation and Reuse, Edited by Lens,P., Zeeman,G., and Lettings,G.,IWA Publishing, London 2001.

[16] Lisa,M.A., Ronnie, A.D.,Williams, F., Winward, G., Shirley-Smith, C., Liu, S., Memon, F.A.,and Jefferson, B., "Constructed Wetlands for Grey Water Treatment", Ecohydrlogy & Hydrobiology, Volume 7, Nos. 3-4, pp. 191-200, UK, 2007

[17] Amr, M., and Abdel-Kaders, "Studying the Efficiency of Grey Water Treatment by Using Rotating Biological Contactors System", Journal of King Saud University - Engineering Sciences, Volume 25, No. 2,pp. 89-95, Saudi Arabia, July, 2013.

[18] Gideon, P., Winward,Lisa, M.A., Williams, R.F., Pidou, M., Jeffrey, P., Stephenson, T., and Jefferson, B., "A Study of the Microbial Quality of Grey Water and an Evaluation of Treatment Technologies for Reuse", Ecological Engineering, Volume 32, No. 2,pp.187-197,1 February, 2008.

[19] Abdel-Shafy,H.I.,El-Khateeb, M.A., andShehata, M., "Greywater Treatment Using Different Designs of Sand Filters", Desalination and Water Treatment,pp.1-6,2013.

[20] Metcalf, and Eddy, "Wastewater Engineering Treatment, Disposal And Reuse", McGraw-Hill, New York, USA, 2010.

[21] Jefferson, B., Palmer,A., Jeffrey, P., Stuetz, R., and Judd, S., "Greywater Characterization and Its Impact on the Selection and Operation of Technologies for Urban Reuse", Water Science and Technology, Volume 50, No. 2, pp. 157-164,IWA, 2004.

[22] Pathan, A.A., Mahar, R.B., and Ansari, A.K., "Preliminary Study of Greywater Treatment Through Rotating Biological Contactor", Mehran University Research Journal of Engineering & Technology, Volume 30, No. 3, pp.531-538, Jamshoro, Pakistan, July, 2011.

[23] Herna´ndez Leal,L., Zeeman, G., Temmink, H., and Buisman, C., "Characterizationand Biological Treatment of Greywater", Water Science & Technology Volume 56, No. 5, pp. 193-200, IWA Publishing, 2007.