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Treatment of grey water by using rotating Biological contactors unit

Sachin Madhavrao Kanawade

Abstract
The need for water is growing with increasing population and the adverse impacts of climate change. Innovative concepts and technologies are urgently needed to close the loop for water. Among the options for innovative water resources, segregation of grey water and reuse receiving crucial attention for decentralized areas as a sustainable approach. Grey water represents substantial portion of household water consumption in volume. Treated grey water to a level complying reuse rules and regulations can be reused for several purposed including agriculture, landscaping and toilet flush. The mathematical model was used to investigate the performance and treatment capability of Rotating Biological Contactors (RBC) to treat the grey water. The GPS-X (version 5.0) simulation program was used in this study to simulate the proposed RBC plant. The proposed Rotating Biological Contactors (RBC) plant is composed of three parts, first is the RBC tank unit, second is the settling tank unit and third is the disinfection tank unit. After the model optimization, three different concentrations of the grey water were used to run the proposed mathematical model. Low, medium and high concentrations of the grey water were used to run the model. The proposed model was verified by using data from RBC experimental pilot plant. The results of this study showed that, The treatment efficiency of the RBC system based on BOD removal was ranged between about 93.0 to 96.0 %, and based on TSS removal was ranged between about 84.0 to 95.0 % for all concentrations of influent grey water. Also, the proposed model results indicated that grey water can be properly treated by RBC system and can be reuse in many purposes after disinfection and sand filtration.

Keywords: Grey Water Treatment; Rotating Biological Contactors; GPS-X; Wastewater Reuse; Biological Treatment.

1. Introduction
Domestic wastewater treatment and reuse is becoming an important field of research in a global context of increasing water scarcity and inadequate sanitation. In the developing world, insufficient water supply and poor sanitation facilities cause thousands of deaths each day, while in developed countries, water wastage is often the norm and ineffective septic and wastewater treatment systems cause pollution of lakes, rivers and groundwater. In parallel, water demand countries to increase, and its availability for agricultural irrigation is a limiting factor for food production in many countries [1]. Source separation of domestic wastewater into grey and black water streams is a strategy for simplifying and decentralizing the wastewater treatment and reuse process. Grey water, which excludes toilet wastes and typically represents 60-70% of liquid waste flows [2]. Conventional centralized water management approach is becoming less suitable due to high investment cost of long sewerage lines, which are sometimes even higher than treatment facilities, high operation and maintenance costs, high amount of good quality water needed for transportation of wastes to long distances and high risks involved. On the other hand, on-sit segregation-collection-treatment-reuse of grey water for residential areas is increasing attention as an element of decentralized approach [3]. Grey water is defined as the low-polluted household streams from showers, bath-tubs and washing machines. [4]. Properly treated grey water can be used potentially for irrigation, toilet flushing and various type of cleaning purpose. Grey water constitutes about 70% of household water consumption, has lower concentration of organic compounds and fewer pathogens as compared to domestic wastewater [5]. Hence, grey water may be treated and reused much easily than composite domestic wastewater for the point of treatment technologies applied and relevant costs. Grey water experiments and implementation practices started over a decade ago, several systems constructed and

operated, some were successful however, one forth of the systems in Germany was assessed as unsatisfactory [6-8]. A wide spectrum of technologies, from very simple to sophisticated systems, can be utilized for grey water treatment and reuse [9]. A number of treatment options including, natural systems, filtration, Rotating Biological Contactor (RBC), Sequencing Batch Reactor (SBR) and Membrane Bioreactors (MBR) have been practiced. UV or chlorination processes are generally used for disinfection purposes in grey water treatment and reuse systems [8,10]. The studies on grey water typically focused on treatment with several technologies to an extent, which satisfy various aspects of reuse/recycle criteria as well as the optimization of treatment efficiency. However, grey water differs from household composite domestic wastewater in character. Hence, the process design and kinetic parameters for attached growth type biological systems operating with grey water are expected to deviate from composite domestic wastewater. The modular program used in this study is GPS-X (version 5.0) which is a modular, multi-purpose modeling environmental for the simulation of municipal and industrial wastewater treatment plants. GPS-X uses an advanced graphical user interface to facilitate dynamic modeling and simulation. GPS-X is also uses the most recent advances in process modeling, simulation technology, graphics and a host of productivity tools that simplify model construction, simulation and interpretation of results.

2. Materials and Methods

2.1 Pilot Plant Configuration and Operation Conditions

2.1.1 Rotating Biological Contactors (RBC) Pilot Plant Mathematical Model

The mathematical model was used to investigate the performance and treatment capability of Rotating Biological Contactors (RBC) to treat the grey water. The GPS-X (version 5.0) simulation program was used in this study to simulate the proposed RBC pilot plant. The GPS-X is a modular, multi-purpose modeling environmental for the simulation of municipal and industrial wastewater treatment plants. Figure 1 shows the general layout of the RBC mathematical model system. The proposed Rotating Biological Contactors (RBC) plant is composed of three parts, first is the RBC tank unit, second is the settling tank unit and third is the disinfection tank unit. The model has the ability to optimize the kinetic parameters of the biological reactions for the proposed model. After the model optimization, three different concentrations of the grey water were used to run the proposed mathematical model. Low, medium and high concentrations of the grey water were used to run the model.

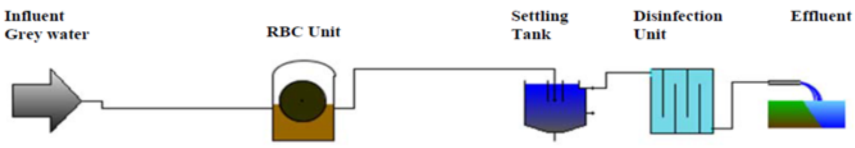

Figure 1 General layout of the RBC model system

The grey water characteristics were based on the study done at Environment Institute [11]. The grey water was collected from lodging buildings whereas the plumbing system was segregated as black water and grey water. A wide range of concentrations of grey water were monitored during the experimental study. Low, medium and high concentrations of the grey water were used to run the model. Also, an experimental Rotating Biological Contactors (RBC) pilot plant was operated during this study. The results of the experimental pilot plant were used in the calibration and verification for the proposed model.

The operation conditions of the RBC pilot plant were as follows

- Average influent flow rate = 400 l/d.
- RBC liquid volume = 0.2 m^3.
- RBC disks area = 16.2 m^2.
- Submerged fraction of biofilm = 40%.
- Maximum biofilm thickness = 0.001 m.
- Mixed Liquor Suspended Solids (MLSS) = 2800 mg/l.
- Clarifier surface area = 0.5 m2, clarifier water depth = 0.40m.
- Disinfection tank volume = 30 l, chlorine dosage = 1.0 mg/l.

2.1.2 Rotating Biological Contactors (RBC) Experimental Pilot Plant System

The grey water used in this study, was collected from lodging buildings whereas the plumbing system was segregated as black water and grey water streams in advance. Kitchen wastewater was included in the grey water system. **Figure 2** shows the schematic illustration of the RBC experimental system. Grey water passed through first a coarse screen (1cm pore opening) and an equalization basin equipped with 3 mm mash size screen before being fed to the RBC unit. The RBC tank included total of 36 discs with 16.2 m2 total disc areas. The RBC unit was operated for a period of 10 months respectively. Peristaltic pumps were utilized to pump the screened grey water to the inlet RBC tank. The flow rate of 400 l/d was applied for the RBC unit. The treated effluent from the RBC unit has been further subjected to UV disinfection process [11].

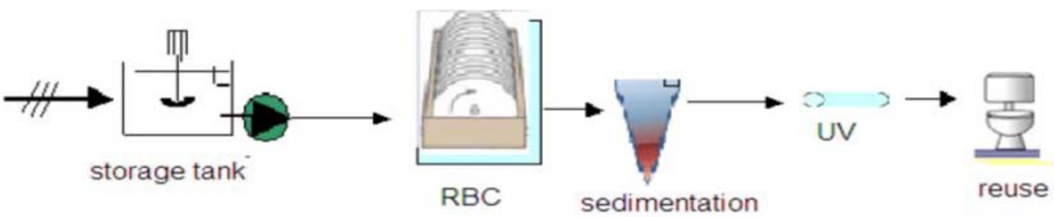

Figure 2 Schematic illustration of the RBC experimental system

Activated sludge taken from an MBR operated with grey water, was added to the RBC reactor to the reactor to acclimatize and accelerate biofilm growth on the discs at the initial stage of the operation. Parameters, related to the biofilm growth (biofilm weight per unit area and BOD5, TSS, TKN, total coliform and turbidity were monitored to appraise the reusability of the effluent on weekly basis. Furthermore, NH_4^+, NO_3^-, T.P were monitored for the process control purpose. The analysis of the monitored parameters was conducted in accordance with the Standard Methods [12].

According to the EPA, suggested guidelines for reuse, especially for the purpose of urban reuse, for all kinds of irrigation, toilet flushing, the concentration of BOD5 should not exceed 10 mg/l, for TSS 5 mg/l, fecal coliform should not be detected in 100 ml sample, and pH should be in the range of 6-9 [13]. The other guidelines, such as WHO guidelines for grey water reuse has higher limits for the relevant parameters [14]. Hence, EPA, suggested guidelines were basically taken into account for the assessment of compliance with the reuse criteria throughout the experimental study. Also, the results obtained throughout the study were compared to the WHO water reuse standards as well. The influent grey water concentrations for the RBC system were ranged form low, medium and high concentrations. **Table 1** shows the influent concentrations of the grey water for the RBC system.

2.2 Influent Grey Water for Both RBC Mathematical Model and RBC Experimental Pilot Plant System

Three grey water concentrations were used as an influent for both RBC model and RBC experimental pilot plant. The grey water concentrations were low, medium and high concentration. **Table 1** shows the influent grey water characteristics for Both RBC Model and RBC Pilot Plant. The influent flow rate for the RBC model and pilot plant was 400 l/d.

Table 1 Influent grey water characteristics for Both RBC Model and RBC Pilot Plant

Parameter	Low concentration	Medium concentration	High concentration
pH	6.9	7.1	7.4
T, ^{0}C	22	22	22
COD_T, mg/l	179	347	525
COD_{Sol}, mg/l	89	214	286
BOD_5, mg/l	72	119	182
Turbidity, NTU	39	103	254
TSS, mg/l	28	79	146
TKN, mg/l	2	8	13
NH_4^+, mg/l	0.6	2.2	5.5
NO_3^-, mg/l	0.0	0.0	0.0
TP, mg/l	3.7	9.8	14.6

3. Results and Discussion

Table 2 shows the summary of the RBC pilot plant mathematical model results. The efficiency of total suspended solids removal TSS were 83.6, 92.8 and 94.8 % for low, medium and high influent concentration respectively. Whereas, the efficiency of BOD removal was 94.2, 95.5 and 95.9 % for low, medium and high influent concentration respectively. Also, the total nitrogen removal efficiency TKN were 58.6 % and 74.3 % for medium and high grey water concentration respectively.

Table 2. Summary of results for the RBC pilot plant mathematical model

Parameter	Low Concentrations			Medium Concentrations			High Concentrations		
	Inlet (mg/l)	Outlet (mg/l)	Eff (%)	Inlet (mg/l)	Outlet (mg/l)	Eff (%)	Inlet (mg/l)	Outlet (mg/l)	Eff (%)
TSS	28	4.59	83.6	79	5.71	92.8	146	7.56	94.8
BOD	72	4.19	94.2	119	5.37	95.5	182	7.56	95.9
TKN	2	2.97	NA	8	3.31	58.6	13	3.34	74.3

Table 3 shows the summary of the RBC experimental pilot plant results. The efficiency of total suspended solids TSS removal were 92.9, 86.1 and 86.3 % for low, medium and high influent concentration respectively. Whereas, the efficiency of BOD removal were 93.1, 94.7 and 95.6 % for low, medium and high influent concentration respectively. Also, the total nitrogen removal efficiency TKN were 85.0, 71.3 and 57.0 % for low, medium and high grey water concentration. It can be concluded form these results that, the efficiency of the BOD removal and total suspended solids TSS removal for the RBC system is high enough to satisfy the treatment requirements for the grey water.

Table 3. Summary of results for the RBC experimental pilot plant

Parameter	Low Concentrations			Medium Concentrations			High Concentrations		
	Inlet (mg/l)	Outlet (mg/l)	Eff (%)	Inlet (mg/l)	Outlet (mg/l)	Eff (%)	Inlet (mg/l)	Outlet (mg/l)	Eff (%)
TSS	28	2	92.9	79	11	86.1	146	20	86.3
BOD	72	5	93.1	119	6.3	94.7	182	8	95.6
TKN	2	0.3	85	8	2.3	71.3	13	5.6	57.0

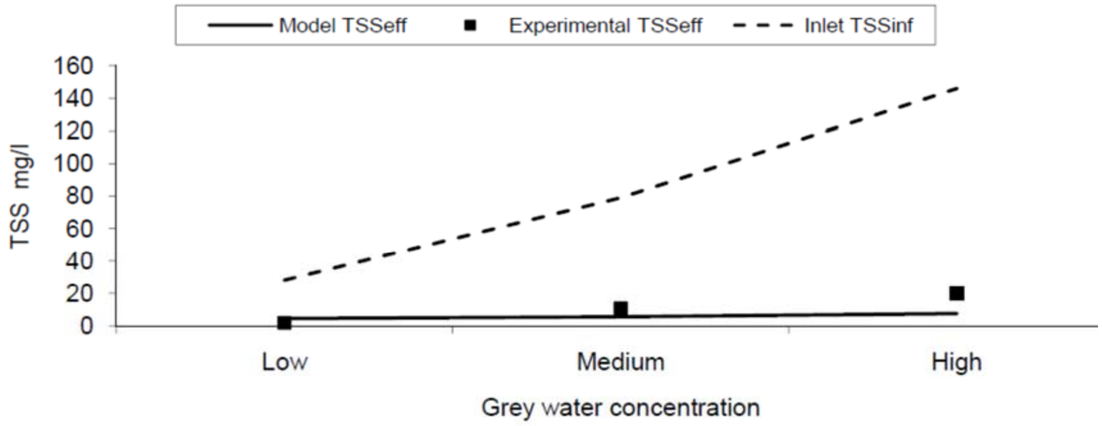

Figure 3 Relation between grey water concentration and TSS concentration.

Figure 3 shows the relation between grey water concentration and total suspended solids concentration. **Figure 4** shows the relation between grey water concentration and the BOD concentration. **Figure 5** the relation between grey water concentration and total nitrogen TKN concentration. It can be concluded from these figures that, the proposed RBC mathematical model is accurate enough to simulate the biological treatment process at the RBC system.

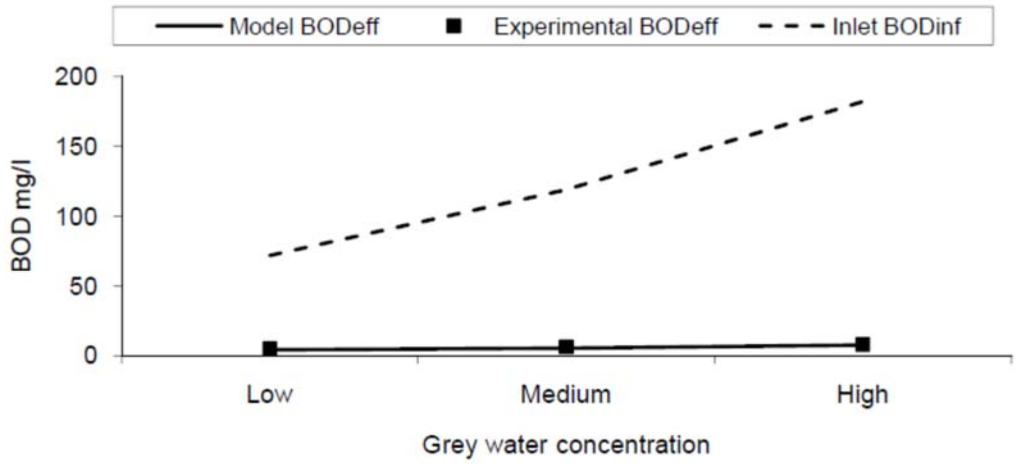

Figure 4 Relation between grey water concentration and BOD concentration.

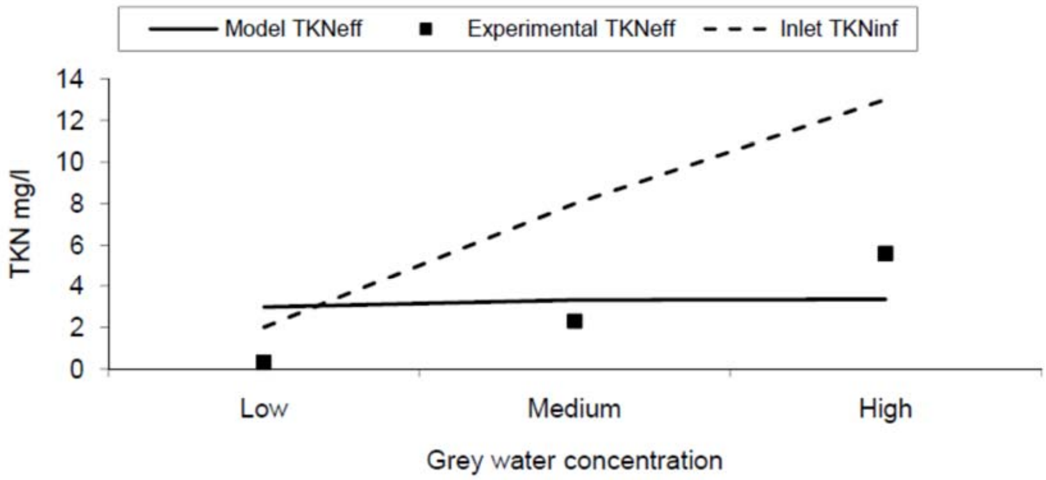

Figure 5 Relation between grey water concentration and TKN concentration.

Figure 6 shows the relation between grey water concentration and the total suspended solids TSS removal efficiency. Also, **Figure 7** shows the relation between grey water concentration and BOD removal efficiency. **Figure 8** shows the relation between the BOD loading rate and TSS and BOD removal efficiency. The inlet BOD loading rate was about 1.78, 2.94 and 4.55 gm BOD/m ^{2}.d for low, medium and high influent grey water concentration respectively. It can be concluded form all of these results that, the removal efficiency of the RBC system increases with the increasing the BOD loading rate up to loading rate about 5.0 gm BOD/m ^{2}.d. The grey water is considered as nitrogen limited for biomass growth, effective mineralization and even nitrification processes occurred for the RBC system without encountering any problem due to the fact that biofilm processes have low biomass yield and very high sludge ages. The ammonia nitrogen loading rate was about 0.015, 0.054 and 0.136 gm NH_4^+ /m^2.d for low, medium and high influent grey water concentration respectively. Whereas, the total nitrogen TKN loading rate was about 0.049, 0.198 and 0.321 gm TKN /m2.d for low, medium and high influent grey water concentration respectively. The treated effluent quality mostly satisfied the reuse criteria of the EPA, suggested guidelines for agriculture and urban usages [13]. However, the criteria were

violated sometimes for total suspended solids TSS due to detached particles from the biofilm although sedimentation was provided. For this purpose, a simple sand filtration unit prior to the disinfection is virtually recommended to comply with the reuse criteria continuously which also guarantee the efficiency of the disinfection process.

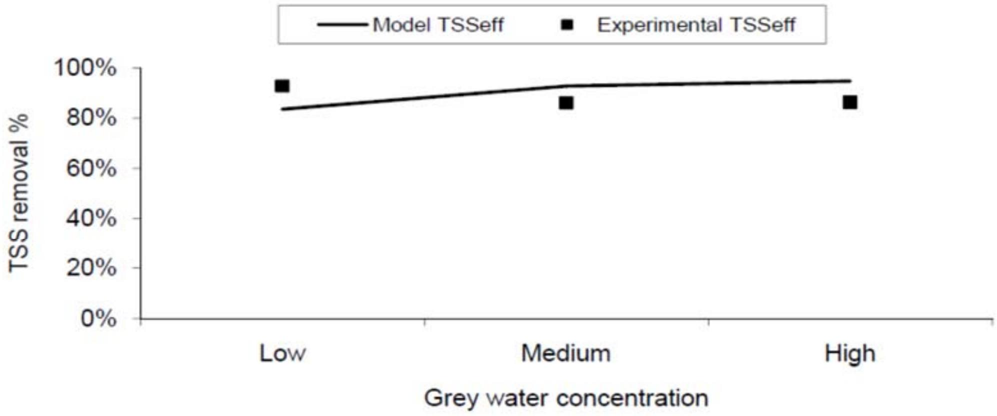

Figure 6 Relation between grey water concentration and TSS removal efficiency.

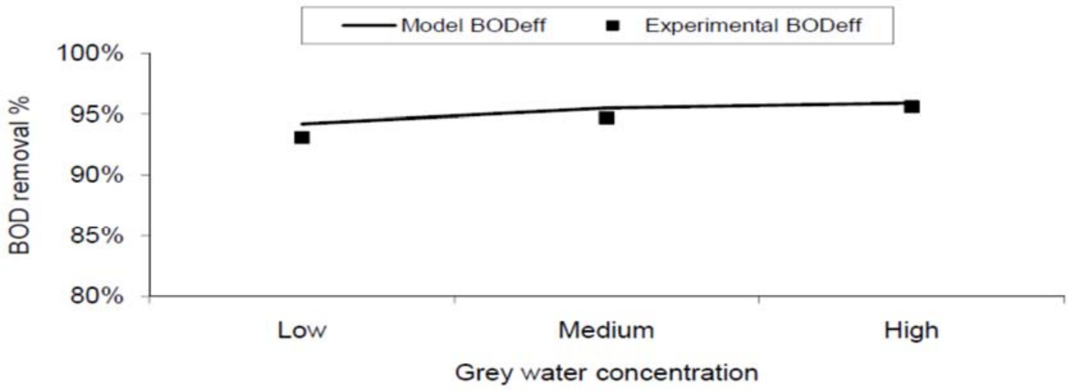

Figure 7 Relation between grey water concentration and BOD removal efficiency

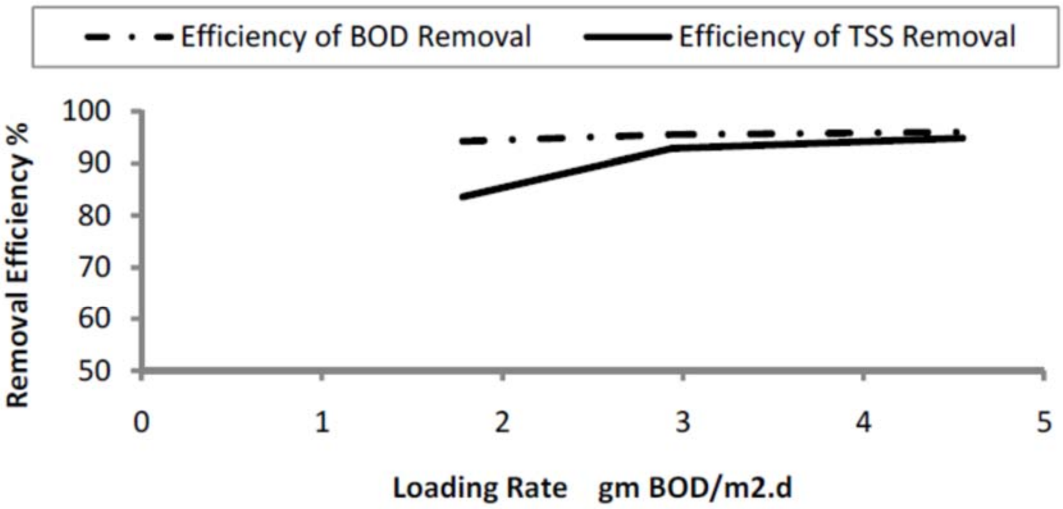

Figure 8 Relation between loading rate and removal efficiency

It should be emphasized that, the pollutant removal efficiency attained for grey water treatment by other technologies like membrane bioreactor MBR virtually is higher than the RBC system especially in terms of COD, BOD and suspended solid concentrations [9]. However, the RBC may be promising method for grey water treatment for reuse purposes considering operational ease, low cost of operation and maintenance without technical personnel requirement and provision of sufficient effluent quality. Also, the energy requirement of the grey water treatment by RBC system is lower than the case of treatment by MBR system.

4. Conclusions

Based on the observation and results obtained from this study, the following points are concluded

- The treatment efficiency of the RBC system based on BOD removal is ranged between about 93.0 to 96.0 %, and based on TSS removal is ranged between about 84.0 to 95.0 % for all concentrations of influent grey water.
- Removal efficiency of the RBC system increases with the increasing of the BOD loading rate up to loading rate 5.0 gm BOD/m^2.d.
- Sand filtration unit prior to the disinfection for the RBC system is virtually recommended to comply with the reuse criteria continuously which also guarantee the efficiency of the disinfection process.
- The results of the RBC proposed model indicated that grey water can be properly treated byRBC system and can be reuse in many purposes after disinfection and sand filtration.
- The RBC system has several advantages over other grey water management technologies in terms of operational cost, operational ease and low technical personnel requirements as compared to the other technologies.

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