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Performance evaluation of grey water treatment using Rotating Biological Contactor (RBC) along with Phytotreatment and future scope for use as drinking water

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ABSTRACT

Grey water forms a major part in our domestic waste water system. Proper Treatment and reuse of grey water can solve a major problem of water scarcity. Grey water is that part of our waste water which is free from fecal matter and contains very low organic content and only few pathogens. It becomes easier to treat grey water discharged from bathrooms, kitchens and laundries. Properly treated grey water can be used in toilet flushing, irrigation, gardening of homes to reduce our water bills. Several treatment technologies have been developed in the past years to evaluate the performance of grey water treatment. Use of Rotating Biological Contactor (RBC) along with a mathematical model was done to analyse the different concentrations of grey water i.e. High, Medium, and low concentrations. The RBC system proved to be efficient in BOD removal and it was between 93% - 96% and TSS removal was between 84% - 95% of all concentrations of Influent grey water. Phytotreatment of grey water was also done by the use of oleaginous plants like rapeseed, soybean and sunflower. The Phytotreatment tests were carried out in 20 L pots in a greenhouse and it presents high removal efficiency of Nitrogen (N > 80%), Phosphorus (P >90%),COD about 90% . Biomass production along with grey water treatment was main finding of this study. The treated grey water can be used after disinfection and Sand Filtration. Efficient Treatment of grey water can comply with water shortage in future.

Keywords: *Wastewater Reuse, Phytotreatment, Grey Water, Rotating Biological Contactor.*

1. INTRODUCTION

Reuse of Grey water is one of the most important contexts in the field of Environmental Engineering. In order to save the earth from the web of water scarcity,reuse of greywater can deal with inadequate sanitation problems and making water available to all corners of the world.Moreover use of grey water in the agricultural fields can deal with the shortage of irrigation water. Grey water is different from black water as it do not contains any fecal matter and grey water constitutes about 60-70 % of domestic waste water (Friedler,2004).

The Grey water is available from our houses discharged from bathrooms, showers and washing machines. Properly Treated grey water can reduce health hazards and can be used in irrigation, toilet flushing etc. The water treated with RBC (Rotating Biological Contactor) system is normally utilized in flushing system. Since the grey water contains little pathogens it requires little efforts only to make it fit for various day to day human activities.

With some modern advancements the treated grey water can be made fit for drinking by using low cost experimental model and further treating the effluent with Reverse Osmosis and UV Treatment. The Treated grey water can be kept along with underground water for about 6 months so that natural forces of purification can act and make the Grey water fit for drinking and also encourage the people to consume such water as it eliminates the sense of toilet water from the minds of consumers.

2. METHODS USED

2.1 Use of Rotating Biological Contactor (RBC) System

A Mathematical model of rotating biological contactor system along with a pilot plant was used to study the performance of grey water treatment. The mathematical model used was GPS-X (version 5.0) so as to simulate the proposed pilot plant. The model along with the pilot plant was run with different concentrations of grey water i.e. High, Medium and low concentrations of grey water. The grey water characteristics were based on the study done at Environment Institute at Tubitak city, Turkey (Baban et al., 2009). The results of the experimental pilot plant were used in the calibration and verification for the proposed model.

The operation conditions of both mathematical model and RBC pilot plant are shown below-

Average influent flow rate= 400 Litres/day.

- RBC liquid volume= 0.2 m^3.
- RBC discs 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 m^2, clarifier water depth= 0.40 m.
- Sludge waste (from sedimentation tank)= 2 $l/m^3/d$, sludge age = 4.0± 0.5 days.
- Hydraulic Load Rate, HLR= 0.03 m^3/m^2 d
- Disinfection tank volume= 30 L, chlorine dosage= 1.0 mg/l.

The kinetic parameters for the RBC model were as follows:

(a) Active heterotrophic biomass:

- Heterotrophic maximum specific growth rate= 3.2 per day
- Readily biodegradable substrate half saturation coefficient =5.0 g COD/m^3
- Aerobic oxygen half saturation coefficient = 0.2 gO_2/m^3
- Anoxic oxygen half saturation coefficient = 0.2 gO_2/m^3
- Heterotrophic decay rate =0.62 per day

(b) Active autotrophic biomass:

- Autotrophic maximum specific growth rate= 0.75 per day
- Ammonia (as substrate) half saturation coefficient

=1.0 gN/m^3

- Oxygen half saturation coefficient = 0.2 gO_2/m^3
- Oxygen half saturation coefficient = 0.04 per day

(c) Hydrolysis:

- Maximum specific hydrolysis rate =2.81 per day
- Slowly biodegradable substrate half saturation coefficient =0.15 gCOD/gCOD.
- Anoxic hydrolysis factor =0.37

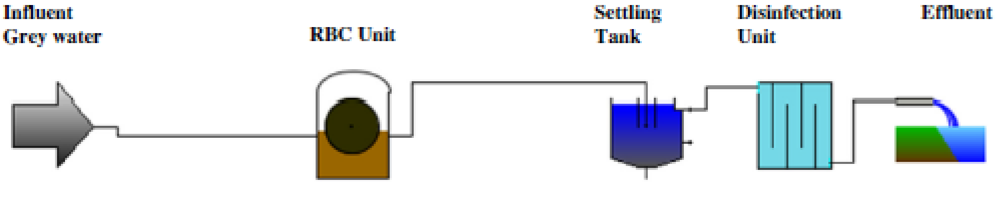

Figure-1: Layout of RBC model

According to the EPA, suggested guidelines for reuse, especially for the purpose of urban reuse, for all kinds of irrigation, toilet flushing, and the concentration of BOD5 should not exceed 10 mg/l, for TSS 5 mg/l, faecal coliform should not be detected in 100 ml sample, and pH should be in the range of 6–9 (EPA, 2004). The other guidelines, such as WHO guidelines for grey water reuse have higher limits for the relevant parameters (WHO, 2006). Hence, EPA, suggested guidelines were basically taken into account for the assessment of compliance with the reuse criteria throughout the experimental study.

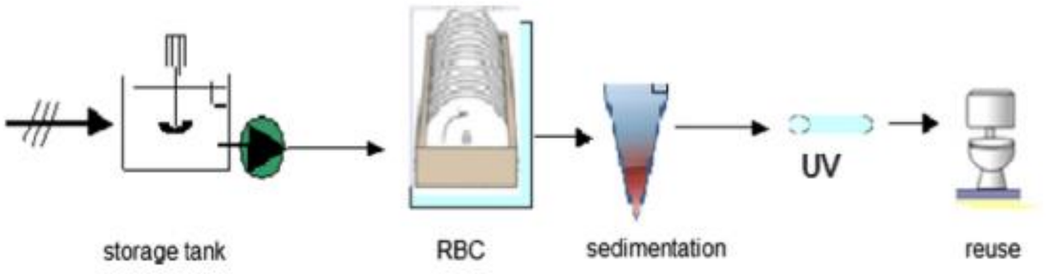

Figure - 2: RBC Experimental Pilot Plant

2.1.1 Influent grey water for both RBC mathematical model and RBC experimental pilot plant system

The water temperature was assumed to be 22 ° C and High, Medium and low concentrations of grey water was used in the study as shown below in the table. The Inflow rate for both RBC mathematical model and pilot plant was taken as 400 Litres/day.

Table - 1: Influent Grey water Characteristics for both RBC model and pilot plant

Parameter	Low concentration	Medium concentration	High concentration
pH	6.9 ± 0.5	7.1 ± 0.5	7.4 ± 0.5
T (°C)	22 ± 2	22 ± 2	22 ± 2
COD_T (mg/l)	179 ± 18	347 ± 35	525 ± 5
COD_{Sol} (mg/l)	89 ± 9	214 ± 21	286 ± 29
BOD_5 (mg/l)	72 ± 7	119 ± 12	182 ± 18
Turbidity (NTU)	39 ± 4	103 ± 10	254 ± 25
TSS (mg/l)	28 ± 3	79 ± 8	146 ± 14
TKN (mg/l)	2 ± 0.2	8 ± 0.8	13 ± 1.2
NH_4^+ (mg/l)	0.6 ± 0.06	2.2 ± 0.2	5.5 ± 0.5
NO_3^- (mg/l)	0.0	0.0	0.0
TP (mg/l)	3.7 ± 0.3	9.8 ± 0.9	14.6 ± 1.4

2.1.2 Results of the Study

- The efficiency of total suspended solids (TSS) removal was 83.6%, 92.8% and 94.8% for low, medium and high influent concentration respectively for RBC model and for RBC pilot plant the efficiency of total suspended solids TSS removal was 92.9%, 86.1% and 86.3% for low, medium and high influent concentration respectively.

- The efficiency of BOD removal was 94.2%, 95.5% and 95.9% for low, medium and high influent concentration respectively for RBC model and for RBC pilot plant efficiency of BOD removal was 93.1%, 94.7% and 95.6% for low, medium and high influent concentration respectively.

- The total nitrogen removal efficiency TKN was 58.6% and 74.3% for medium and high grey water concentration respectively for RBC model and for RBC pilot plant total nitrogen removal efficiency TKN was 85.0%, 71.3% and 57.0% for low, medium and high grey water concentration respectively.

Table - 2: Results for RBC 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 ± 3	4.59 ± 0.46	83.6	79 ± 8	5.71 ± 0.55	92.8	146 ± 14	7.56 ± 0.75	94.8
BOD	72 ± 7	4.19 ± 0.42	94.2	119 ± 12	5.37 ± 0.53	95.5	182 ± 18	7.56 ± 0.73	95.9
TKN	2 ± 0.2	2.97 ± 0.30	NA	8 ± 0.8	3.31 ± 0.33	58.6	13 ± 1.2	3.34 ± 0.34	74.3

Table - 3: Results for 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 ± 3	2 ± 0.2	92.9	79 ± 8	11 ± 1.0	86.1	146 ± 14	20 ± 2	86.3
BOD	72 ± 7	5 ± 0.5	93.1	119 ± 12	6.3 ± 0.6	94.7	182 ± 18	8 ± 0.8	95.6
TKN	2 ± 0.2	0.3 ± 0.03	85	8 ± 0.8	2.3 ± 0.2	71.3	13 ± 1.2	5.6 ± 0.5	57.0

2.2 Phytotreatment of Grey water

The phytotreatment of grey water was done by the use of oleaginous plants (Used in Biodiesel Production).The plants species used in this study were Brassica napus (rapeseed), Glycine max (soybean) and Helianthus annuus (sunflower). The phytotreatment tests were carried out in 20 L pots filled with a layer of 30 cm sandy substrate having a mixture of sand, silt and clay. The experiment was carried out at the Environmental Engineering Centre, Department of Industrial Engineering, University of Padova, where the Aquanova system has been implemented (Lavagnolo, M.C., et al. 2016).The total number of pots which were used are 24 (8 for each plant species. For each plant species 4 pots were used in the test aur remaining 4 were used as control units).The pots were kept in a greenhouse having and environmental condition of average daily temperature of 24 ^{o}C and average night temperature of 12 ^{o}C and were exposed to light for about 14 hours. In starting the plants were irrigated using tap water and Hoagland’s solution (Hoagland and Arnon, 1950) upto the Acclimatization phase and after that nitrogen load was gradually increased by the use of different combinations of grey,yellow and kitchen waters. The remaining pots (four of each species) were watered with tap water and Hoagland's solution and used as control units according to a well-established procedure (Holmes, 1980; Hocking and Steer, 1983; Salvagiotti et al., 2008). In a similar experiment, Sawaittayothin and Polprasert (2007) demonstrated that the minimum HRT must be between 5 and 8 days, depending on the contaminants to be removed. The experiment was extended for the entire vegetative period of the three species until plant senescence was reached (end of phase IV). During the research phases the outflow streams from the different pots were sampled and analysed twice a week, according to the Italian standard analytical methods (CNR-IRSA,197 29/2003), with four replicates.

Table- 4: Feeding Mixtures used in phytotreatment

Phase	Duration (days)	Composition of the inflow water (%, V/V)
Acclimatization	19	tap water + nutritive solution (Hoagland solution)
	10	50% tap water + 50% GW
Phase I	18	100% GW
Phase II	10	49.95% GW + 49.95% KW + 0.1% YW
Phase III	10	49.9% GW + 49.9% KW + 0.2% YW
Phase IV	10	49.75% GW + 49.75% KW + 0.5% YW

GW = grey water, KW = kitchen water, YW = yellow water.

Table- 5: Influent Water quality (Expressed in mg/L) during the Research period

Phases	COD	TKN	$N\text{-}NO_3$	Ptot	Cl^-	SO_4^{2-}	TS	VS	MBAS
Acclimatization	5 ± 1.2	0.3 ± 0.1	41.0 ± 8.8	3.1 ± 0.2	3.7 ± 0.2	48.0 ± 14	440 ± 11	150 ± 2	–
	23 ± 9	0.9 ± 0.2	0.07 ± 0.03	3.3 ± 0.1	13.4 ± 2.4	12.0 ± 1.6	278 ± 18	147 ± 3	0.13 ± 0.02
Phase I	48 ± 17	1.5 ± 0.4	0.01 ± 0.10	3.1 ± 0.1	27.6 ± 1.1	26.0 ± 3.3	401 ± 10	133 ± 6	0.30 ± 0.02
Phase II	528 ± 49	4.5 ± 1.6	0.60 ± 0.10	4.5 ± 0.7	29.8 ± 8.1	19.5 ± 3.7	703 ± 38	499 ± 69	57.59 ± 25.98
Phase III	530 ± 48	7.8 ± 2.3	0.60 ± 0.10	4.9 ± 0,8	31.4 ± 8.2	19.6 ± 3.7	711 ± 40	502 ± 70	57.53 ± 25.95
Phase IV	540 ± 47	17.7 ± 4.5	0.60 ± 0.10	5.9 ± 1.9	36.1 ± 8.3	20.3 ± 3.8	737 ± 41	512 ± 73	57.36 ± 26.00

COD: chemical oxygen demand; TKN: total Kjeldahl nitrogen; MBAS: Methylene Blue active substances; VS: volatile solids; TS: total solids.

2.2.1 Efficiency of Removal

The following mathematical formula was used in the calculation of removal efficiency for different parameters –

$$\eta = (V_{in} \cdot C_{in} - V_{out} \cdot C_{out})/(V_{in} \cdot C_{in}) \cdot 100\%$$

Where-

V_{in} (L/week) = Influent Volume

V_{out} (L/week)= Effluent Volume

C_{in} (mg/L) = Influent Concentration

C_{out} (mg/L) = Effluent Concentration

2.2.2 Results of Study

- High Nitrogen Removal Efficiency almost greater than 80 %.
- Nitrogen concentration in the outflow was constantly below 10 mg/L.
- Throughout the entire experiment, mean phosphorous load values ranged between 30 mg P/m^2/day (sunflower) and 35 mg P/m^2/day (rapeseed and soybean) being within the phosphorous plant demand (Holmes, 1980).
- High Nutrient removal and outflow concentration of each parameter was below 1 mg/L .
- COD always remained below 100 mg/L and it reduces to 1 mg/L during initial stage.
- The good COD removal efficiency is related to the synergic effects of the chemical, physical and biological processes occurring in the plant-substrate system (sedimentation, filtration, adsorption in the substrate, biodegradation of the organic matter and uptake by plant roots), as reported by Duggan (2005).
- Generally, COD, N and P removal rates are higher than those reported in previous studies (Keffala and Ghrabi, 2005;Khan et al., 2009)
- Methylene Blue Active substances (MBAS) removal efficiency was above 95 % for all plant species.

Table – 6: Input and output concentrations of parameters and removal efficiency for plant species

Parameter	Species	IN		OUT		η (%)
		Min–Max	Average	Min–Max	Average	
Cl^- (mg/L)	Rapeseed	27.6–44.4	30.8	23.6–28.5	24.4	21
	Sunflower			22.9–27.7	23.6	23
	Soybean			26.1–31.5	26.9	13
SO_4^{2-} (mg/L)	Rapeseed	19.5–29.3	21.8	15.1–16.9	15.8	23
	Sunflower			13.7–15.4	14.4	30
	Soybean			13.2–14.8	13.9	32
TS (mg/L)	Rapeseed	401–778	732	384–542	485	61
	Sunflower			330–440	399	79
	Soybean			520–684	587	68
VS (mg/L)	Rapeseed	133–585	505	118–280	223	77
	Sunflower			98–160	124	90
	Soybean			136–402	281	79
Cu (μg/L)	Rapeseed	27.0–82.9	112.0	10.0–12.0	11.0	90
	Sunflower			<10.0	10.0	93
	Soybean			<10.0	10.0	93
Fe (μg/L)	Rapeseed	31.0–1150.0	647.0	10.0–404.0	160.0	86
	Sunflower			10.0–510.0	25.0	100
	Soybean			10.0–488.0	170.0	99
MBAS (mg/L)	Rapeseed	0.30–83.57	43.5	0.1–1.3	0.8	98
	Sunflower			0.1–1.5	0.9	98
	Soybean			0.1–1.3	0.8	98

IN: input concentration; OUT: output concentration; η: removal efficiency; MBAS: Methylene Blue active substances.

2.3 Modification of Laboratory Scale Grey water treatment plant to use treated grey water as drinking water

A laboratory scale grey water treatment plant was used to treat grey water and further it can be used as drinking water by the application of Reverse Osmosis (RO) system and Reclamation of Water in ground water for about 6 months. This laboratory scale model is best alternative and cost effective in rural areas of India. This laboratory scale treatment plant was used in small college campus in Maharashtra (India). The grey water was collected from residential hostels,laundries,bathrooms and basins. Water is becoming a rare resource in the world. In India alone the International Water Management Institute (IWMI) predicts that by 2025, one person in three will live in conditions of absolute water scarcity (IWMI, 2003).

The laboratory scale grey water treatment plant which was used in this study (Saroj B. Parjane et al,2011) was designed with 180 litres/hr capacity and it was equipped with 4 stages of primary settling (20 Litres), Aeration (15 litres), Agitation (15 litres) and Filtration unit of 20 litres capacity. The collected grey water was sent to primary settling unit by a 0.5 HP pump . The Gravitational force was used to transfer the water below to each unit. The agitation unit was equipped with 0.18 m diameter agitator and 0.125 HP pump.

The filter beds were made of sand,charcoal,coarse bricks and wooden saw dust and coconut shells bed. The materials used in this filter beds were cheaply available and are low cost energy driven. The depth of eachbed were selected as 0.15 m, 0.1 m, 0.2 m, 0.15 m and 0.2 m for sand, bricks, charcoal, saw dust and coconut shell covers respectively set from bottom to top in the filtration unit.

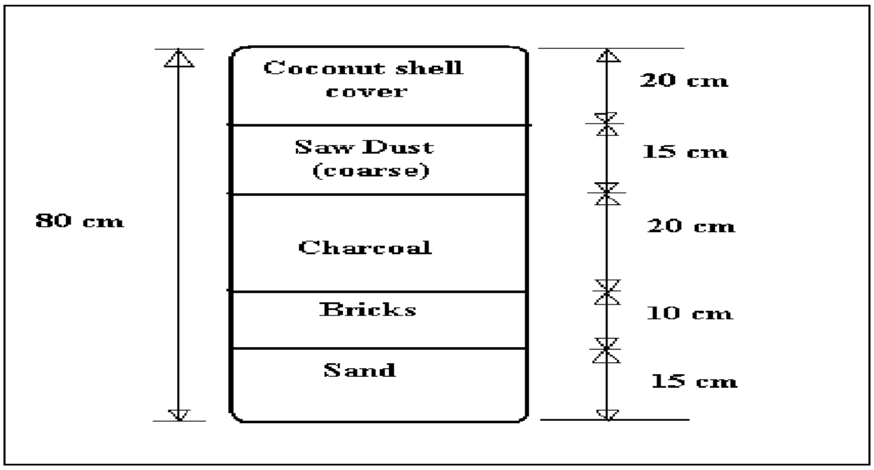

Figure- 3: Filter Media used in filter bed

Figure- 4: Laboratory Scale grey water treatment plant

2.3.A Results of the study

- The 8 samples were analysed and it was found that the organic load was 327 COD mg/L.
- 76% dissolved and 24% suspended particles was found in grey water.
- 83 % of organic load was removed and 46 % anions and 49 % cations were found to be adsorbed by the natural adsorbents used in filtration.
- Potassium, Magnesium and calcium were completely removed from water.
- Effluent quality was better in summers and winters.
- There is sufficient level of phosphorous present in treated water which is good for plant growth.
- The concentration of salts, detergents and minerals are reduced, so there no potential for adverse impacts on the soil and plants.
- Alkali Loving plants are not affected.

Table – 7: Water Quality Parameters of inflow and outflow

Sr. No.	Parameters	Raw water	Filtered water
1	pH	8.12	7.43
2	Total Hardness (mg/lit)	374	187
3	COD (mg/lit)	327	58
4	TDS (mg/lit)	573	172
5	TSS (mg/lit)	184	32
6	Oil and grease (mg/lit)	7.2	0.24
7	Fluorine (mg/lit)	0.82	0.43
8	Chlorine (mg/lit)	37.9	21.47
9	Nitrites (mg/lit)	0.08	00
10	Nitrates (mg/lit)	0.67	0.21
11	Phosphates (mg/lit)	0.012	00
12	Sulphates (mg/lit)	21.3	10.66
13	Sodium (mg/lit)	32.28	17.11
14	Potassium (mg/lit)	4.52	1.98
15	Magnesium (mg/lit)	0.11	00
16	Ammonia- nitrogen (mg/lit)	0.79	0.21
17	Calcium (mg/lit)	0.13	00

The Above Treated water quality parameters are low enough as per IS 10500 (Drinking Water Specifications) and hence by the further treatment of effluent by Reverse Osmosis and UV treatment this water can be made fit for drinking and can be used in potable form. The Treated Effluent should be kept below the ground with underground water so that natural forces of purification can act on this water and moreover it will also eliminate the sense of Toilet water from the minds of public and it will encourage the public to consume such water. The treated effluent is kept with underground water for atleast 06 months.

Table – 8: Performance of Grey water treatment plant in 3 different seasons

Sr. No.	Parameters	Percentage removal of parameter		
		Winter	Spring	Summer
1	Total Hardness	60.5	49.3	56.2
2	COD	90.8	82.1	89
3	TDS	80	71.9	81.2
4	TSS	89.9	85.3	89.2
5	Oil and grease	97	95	97
6	Fluorine	52.9	48.8	51.3
7	Chlorine	49	45.4	47.6
8	Nitrites	99.9	96	99.9
9	Nitrates	74.8	67.9	71.6
10	Phosphates	99.9	92	99.8
11	Sulphates	80.2	48.7	71.3
12	Sodium	72.2	51.7	69.1
13	Potassium	70.3	59.4	62.5
14	Magnesium	100	98.1	100
15	Nitrogen	82.8	76.1	83.5
16	Calcium	100	91.2	98.5

2.3.B Comparison with previous studies

Table- 9: Comparison between present study and previous research findings

Sr. No.	Author and year	Treatment method	Parameters removal efficiency
1	Gross et al. (2007) [15]	Physical (Recycled Vertical Flow Constructed Wetland)	TSS(98%), BOD(100%), COD(81%), TP(71%), TN(69%), Fecal coliform(99%)
2	Gross et al. (2007) [16]	Biological (Recycled Vertical Flow Bioreactor)	COD(89%), NO_3-N(50%), TAN(16%), TSS(95%), Boron, Anionic Surfactants(100%)
3	Seo et al. (2007) [17]	Biological (Activated Sludge) Physical (Coarse pore filtration)	Organic-TOC & BOD(95%), TN(50%), TP(85%), SS
4	Gual et al. (2008) [18]	Physical (Sand filtration) Chemical (Chlorination)	pH, SS(28%), Turbidity(18%), TOC(20%), TN, COD(25%)
5	Kim et al. (2009) [19]	Physical (MF), Chemical (Oxidation)	pH, color(98%), turbidity(99%), COD(99%), SS(99%)
6	Colmenarejo et al. (2009) [20]	Physical (Extended aeration), Biological (Activated Sludge)	Ammonia, TSS(82%), COD(64%), BOD(55%)
7.	Present study	Physical (sedimentation, clarification and filtration) Chemical (oxidation)	Hardness (60%), COD (91%), TDS (81%), TSS (90%), oil and grease (98%), Nitrates (75%), Nitrites (100%), Cations (49%) and anions (46%)

3. CONCLUSIONS

The RBC system proved to be excellent in BOD and TSS removal from the grey water. The BOD removal was between 93-96 % and TSS removal was between 84-95 % for all concentrations of grey water used i.e. High, Medium and Low concentrations grey water but it was important to note that this removal efficiency increases with the increasing BOD loading rate upto 5.0 g BOD/m^2 d. The Phytotreatment by the use of oleaginous plant have great efficiency in COD and Nitrogen Removal.The COD removal in phytotreatment was such that it always remained below 100 mg/L in the outlet while good nitrogen removal aims at producing large amount of biomass which further enhances the productivity of soil. It was important to note that the MBAS (Methylene Blue Active Substances) which is mainly present in kitchen water is removed with an efficiency of 95% in phytotreatment. Sunflower has the highest removal efficiency while Rapeseed has the lowest removal efficiency but the biomass production in rapeseed was the largest. The main advantage of phytotreatment is that, not only removal of contaminants are being done from the grey water but it also encourages plant growth. RBC system requires disinfection along with sand filteration but phytotreatment has no such needs.The laboratory scale pilot plant is low cost,environmental friendly model which can not only treat grey water but it has a high efficiency of making the grey water to be used as drinking water. The effluent obtained by laboratory scale plant was of good quality and it has almost comply with the drinking water standards (IS 10500) and further treatment with reverse osmosis and UV treatment can convert grey water into potable water and no doubt if such alternatives are made available all over the world then the water scarcity problem can be reduced to minimum by 2025.

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