

Efficiency of Degreasing / Settling Tank Followed by Constructed Wetland for Greywater Treatment

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THE PRESENT study deals with real greywater. The objective of this study is to investigate the treatment of greywater for the purposes of reuse. Greywater treatment was examined first to determine the optimum degreasing / settling time. Further treatment by hybrid constructed wetland was examined. Efficient removal of the pollutant parameters was achieved. The experimental method involves evaluation of the treated effluent to reach the allowable limits of water reuse according to "Egyptian Environmental Association Affair, EEAA". Final removal rates reached 87%, 83%, 88%, 91%, 36%, 92%, and 58% for the TSS, COD, BOD₅, TP, NO₃, oil & grease and TKN, successively. The *E. coli* count and the number of cells or eggs of Nematode in the final effluent reached 100/ml and "1 egg/L", respectively.

Keywords: Sewage separation, Degreasing, Settling, Hybrid constructed wetlands and Greywater treatment .

Most of the Arab countries are located in arid and semi-arid zones known for their scarcity of annual rainfall, very high rates of evaporation and consequently extremely insufficient renewable water resources. Sustainable management of water resources is a must, as water scarcity is becoming more and more constraint impeding the economic growth of many countries in the region⁽¹⁻³⁾.

Sustainable water management strategies are considered to be the key solutions to cope with the issues of shortage of water and reuse⁽²⁾. The increasing water shortage reported over the past decade is caused primarily by the growing population combined with lifestyle changes, especially in urban areas. This result leads to increase the conflict between agricultural and other water uses. Sustainable management is currently becoming a dominating approach, focusing on long-term research objective of closed loop recycling. To close between demand and supply, non-conventional water resources have to be developed. One

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of these resources is domestic wastewater. Hence, reclaimed wastewater is an interesting non-conventional resource to reduce water shortage especially in arid areas⁽³⁾.

Greywater is defined as wastewater without any input from toilets or heavily polluted industrial wastewater and generally includes sources from baths, showers, hand washing basins, washing machines, dishwashers and kitchen sinks⁽⁴⁾. Municipal wastewater separation into black and greywater proved to be an efficient system to prevent the contamination of greywater, reduce the volume of fecal contaminated wastewater as well as eliminating the cost of treatment⁽¹⁾.

On-site greywater reuse has the potential to play a significant role. Some technologies such as membrane bioreactors "MBR" or sequencing batch reactors "SBR" have demonstrated the capacity to produce high quality treated effluent^(5, 6). Most greywater treatment systems installed are based on degreasing tanks in combination with constructed wetlands^(7, 8). However, cost, application to scale and the relatively low public perception may limit their application in small communities especially in rural areas of developing countries "arid and semi-arid regions".

In urban areas the most feasible greywater reuse option is for toilet flushing, which can reduce individual in-house net water demand by 40–60 L/d PE. If this practice becomes widespread, reduction of 10–25% in urban water demand can be achieved. For example, 30% of houses having greywater reuse units installed, greywater reuse for toilet flushing in the domestic sector could save about 50 MCM/y in Mediterranean countries⁽⁹⁾. Additionally, greywater contains low nutrients concentrations, ranging from 5 to 22 mg/l of total nitrogen and 0.2 to 3.9 mg/l of total phosphorus, an easily biodegradable organic content and a relatively low pathogens content⁽¹⁰⁾. For these reasons, greywater is much easier to treat and safer to recycle for water usages that do not need potable water quality, such as toilet flushing, urban landscaping or road washing.

In such communities, simple low-tech and efficient systems, such as constructed wetlands "CW", may be more appropriate. CWs treatment can be defined as a man-made, engineered wetland area specifically designed for the purpose of treating wastewater by optimizing the physical, chemical and biological processes that occur in natural wetland ecosystems. CW can provide economical on-site wastewater treatment that is both effective and aesthetically pleasing⁽¹¹⁾.

A wide spectrum of technologies, from very simple to sophisticated systems, can be utilized for greywater treatment and reuse⁽¹²⁾. The greywater treatment needs both physical and biological processes for removal of particles, dissolved organic-matter and pathogens⁽¹³⁾. Recently, many researchers have studied the greywater treatment either by application of high-rate aerobic systems, such as the rotating biological contactor, fluidised bed⁽¹¹⁾, or by application of low-rate systems, like "slow sand filter"⁽¹³⁾. Most of the time, the wetlands can be

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constructed with local materials which lowers the construction cost significantly. Furthermore, these treatment systems are good at removing not only pathogenic and nutrients but also toxic metals and organic pollutants⁽¹⁴⁾. Further investigations for the treatment of greywater for the purpose of reuse were carried out by many authors^(15,16).

Objective of this Study

The present study focuses on the treatment of greywater by the degreasing / settling process followed by hybrid constructed wetland “constructed wetland horizontal flow (CWHF) and constructed wetland vertical flow (CWVF)” as simple, low cost, low energy and friendly techniques for the urban and decentralized areas. The experimental method involves monitoring of specific greywater constituents under varying operating conditions in the different degreasing / settling periods followed by the hybrid constructed wetland for assessing the water quality produced from such system.

Material and Methods

Sources of raw greywater

Municipal wastewater is separated into Black “B” and Grey “G” water segregated and collected from one building across the Training Demonstration Centre “TDC” site in the National Research Centre “NRC”, Cairo, Egypt. This building consists of two separated sides. Each side consists of five apartments. One side is presently connected to the TDC site as separated B and G water manholes. The collected greywater “G” is the subject of the present study. It includes wastewater from baths, showers, hand wash basins, washing machines, dishwashers and kitchen sinks.

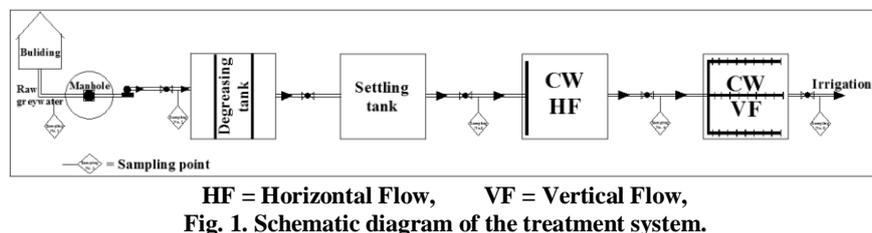
Analytical and measurement for greywater

The physical and chemical characteristics of the raw greywater were determined on weekly basis. Meanwhile, the physical and chemical characteristics of the examined greywater before and after degreasing/ settling tank as well as before and after the hybrid constructed wetland through all the study were carried out according to the American Public Health Association “APHA”⁽¹⁷⁾.

System configuration

The pilot plant

Two-step successive degreasing / settling tanks were constructed as a pre-treatment to remove oil & grease, larger particles, and hair. The effluent from the settling tanks was then fed into the hybrid constructed wetland tanks (CWHF and CWVF). The schematic diagram of the treatment systems is shown in Fig. 1.



Degreasing / settling tank

The degreasing / settling tanks are made of polyvinyl chloride “PVC” with a capacity of 0.7 m³ each. The dimensions of each tank are: 1.00 m height, 0.90 m width and 1.00 m length. The reactor is a rectangular basin raised from the ground surface about four meters. The first tank (degreasing) consists of three chambers 0.3 m in length, 0.9 m in width and 1.00 m in depth separated with baffles at the dimensions of 0.4m, 0.3m. The outlet is then directed to the second tank (settling). These chambers provide the undisturbed area necessary for settling. The detail of settling tank is shown in Fig. 2. The flow rate of the greywater influent to the settling tank is 225 liters/ hr with Surface Overflow Rate “SOR” about 2.5 meter /hour, and the retention time of 1.5 hr. The examination of the removal efficiency was undertaken at different settling times; 1.5, 3.0 and 4.5 hr.

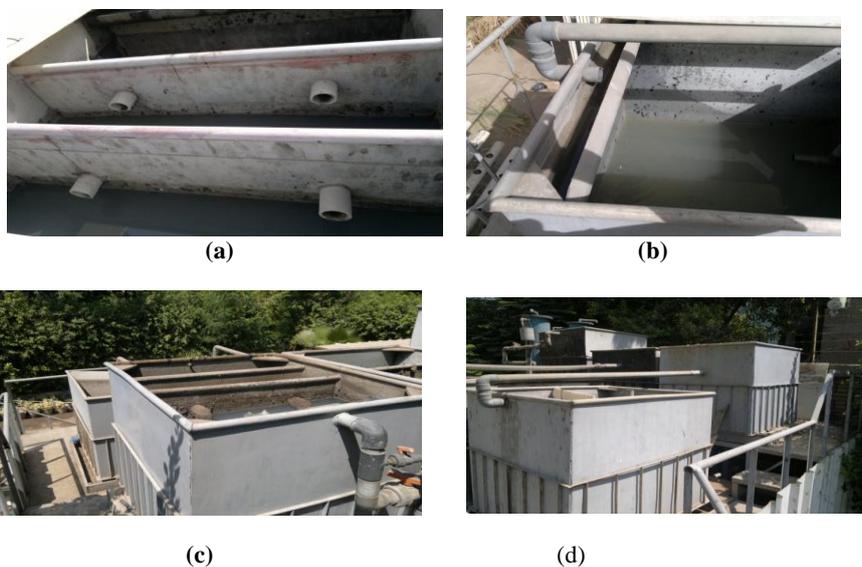


Fig. 2. Degreasing tank followed by settling tank.

(a) Degreasing tank (top view) (b) Settling tank (top view)
 (c) Degreasing and settling tank (top view) (d) Degreasing and settling tank (side view) .

Constructed wetland unit

The design and operating conditions for the treatment of the greywater through the constructed wetland are represented in Table 1.

TABLE 1. Dimensions and operating conditions of the constructed wetland for greywater.

Dimensions and Materials	
No. of units	2
Length	1.2m
Width	1m
Water depth	0.50 m
Plant	<i>Phragmites australis</i>
No. of rhizomes / m ²	3
Substrate	Sand (0.20~0.45) mm, Rice straw (15kg/m ³), and Small gravel (0.5~1.0) mm
Metal piping inlet and outlet	PVC
Release and retain greywater	Valve
Operating conditions	
Hydraulic retention time (HRT)	2.2 d
Hydraulic loading rate (HLR)	430 m ³ /ha. d
Organic loading rate (OLR)	271 kg BOD/ha/d, 356.4 kg COD ha/d

The Vascular plant of the constructed wetlands

'*Phragmites australis*' or "Reed Grasses" as the common reeds in Egypt was namely used as the main plant in the constructed wetland. The rhizomes were collected from a near-by marshland, washed several times with distilled water prior to use and planted at the density of 3 rhizomes/m².

Substrate of CW

The constructed wetland unit was fed continuously with the effluent of settling tank. The wetland unit was manufactured from non-transparent PVC. The substrate was arranged in three layers: sand, rice straw and gravel. The average granular size for sand used in the experimental work is 0.35 mm, height 10 cm, the average height of rice straw about 15 cm, density 15kg/m³, and the average granular size for gravel is 0.75 mm and height of 25 cm.

Calculations of hydraulic retention time "HRT" and organic loading rate "OLR"

Calculation of flow rates and HRT of wetlands was based on the following equation⁽¹⁸⁾

$$Q = (A * d * \eta) / t \quad (1)$$

where:- Q = discharge flow (m³/day), A = surface area (m²)
d = water depth of the system (m), η = porosity of the system (0.4)
t = detention time (day)

by substituting in the equation: t = ((1.2*1.0)*0.5*0.4)/0.11

then, (HRT) was 2.2 days

Meanwhile,
$$OLR = (C * d * \eta) / t \quad (2)$$

where:- OLR = organic loading rate (kg BOD/ha/day), C = BOD concentration of the influent (mg/l), d = water depth of the system (m), η = porosity of the system, t = detention time (day) Then, OLR was 270.91kg / BOD₅ / ha / day

Description of the treatment system

The constructed wetland associated in the biological treatment had elements of aeration and plants. The biological treatment is within the aerobic bacterial growth. These bacteria grew naturally and were responsible for decomposition of suspended/ dissolved organic matter. Finally, this treated greywater was then available for gardening purposes from and to enhance the biodegradation of any organic contamination. The Hydraulic Retention Time "HRT" of the system was 3 days, as was shown in Fig. 1.

The constructed wetland is consisted of two series with a retention time of three days. Subsurface horizontal flow "HF" and subsurface vertical flow "VF" systems have different advantages. Two stage HF-VF hybrid systems achieve good removal of BOD₅, COD and TSS but not total nitrogen because of low denitrification in the last VF stage⁽¹⁹⁾. Starting a hybrid CW with a horizontal bed system means that BOD₅ will be removed and prevented from interfering with nitrification in the vertical flow stage. Each series consists of three beds, one planted with reed, rice straw and sand with gravels. Each wetland bed was 0.6 m³; with 0.75 mm average diameter of small gravel as a supporting medium. A plastic basin was placed for this study to prevent water contamination. An inlet and outlet zone, each 20 cm width, consisting of medium gravel 1~ 2.5 mm diameter, was used to eliminate the effects of the inlet and outlet. Each bed had a polyvinyl chloride "PVC" inlet pipe at its top, ending with horizontal drainage pipe, 50 mm diameter. The influent into each bed was controlled every day by measuring the flow rate and adjusting the valve to maintain a continuous daily flow rate. The schematic diagram of CW is shown in the Fig. 3.

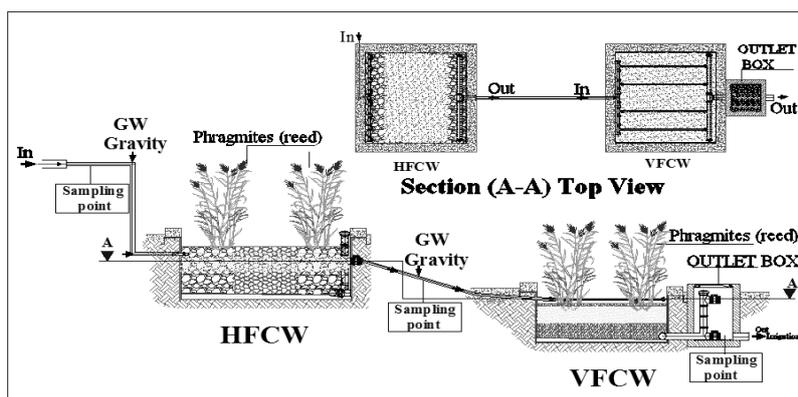


Fig. 3. Schematic diagram of hybrid constructed wetland treatment system.

Results and Discussion

Characteristics of raw greywater

The characteristics of the raw greywater are given in Table 2. The analysis showed that the concentration of physical, biological and microbiological parameters are within the medium levels.

TABLE 2. Characteristics of raw greywater.

Parameter	Unit	Min. value	Max. value	Average
pH	---	5.75	7.91	6.65
Electrical Conductivity (EC)	ms/cm	522	904	682
Temperature	°C	24.51	28.81	26.88
Total Suspended Solids (TSS)	mg/L	55	131	90
Chemical Oxygen Demand (COD)	mg O ₂ /L	297	523	387
Biological Oxygen Demand (BOD ₅)	mg O ₂ /L	145	388	293.4
Total Phosphates (T. P.)	mg/L	8.4	11.8	10.42
Nitrates (NO ₃)	mg/L	0.39	0.48	0.40
Total Kjeldahl Nitrogen (TKN)	mg/L	17	29	27
Oil & Grease	mg/L	92	155	115
Adjusted Sodium Absorption Ratio (SAR _{adj})	%	19.22	33.05	23.15
Number of cells or eggs of Nematode	Egg/L	ND	1	---
<i>E.coli</i> count	100/ml	ND	<100	---

ND = Not detected, Min. = minimum, Max. = maximum.

Degreasing / settling tank

The examined settling times were 1.5, 3.0 and 4.5 hr. Results indicated that the longer the settling time is, the highest reduction of pollution parameters is (Table 3). At the settling time 3.0 hr, greywater removal efficiencies reached 65.1%, 17.0%, 18.5% and 24.4% for the TSS, COD, BOD₅ and oil & grease, respectively. By increasing the settling time to 4.5 hr, better removal efficiency could be achieved namely; 66.5%, 40.3%, 38.5% and 50.2%, successively. TSS results reported the best achieved removal parameter figures, namely 55.9, 65.1 and 69.77% at 1.5, 3.0 and 4.5 hr settling time, respectively. It is worth noting that the oil & grease parameter was mostly removed after 4.5 hr⁽²⁰⁾.

TABLE 3. Effect of different settling times on the average characteristics of raw GW.

Parameter	Raw Grey water	Settling Time					
		1.5 hr		3.0 hr		4.5 hr	
		Con. (Average)	% R	Con. (Average)	% R	Con. (Average)	% R
Temperature °C	24.93	24.80	---	25.1	---	24.9	---
pH	7.63	6.59	---	6.82	---	6.85	---
EC (ms/cm)	906	840	7.30	781	13.80	773	14.70
TSS (mg/L)	137.53	60.60	55.94	55	60.00	40	70.91
COD (mgO ₂ /L)	464	397	14.44	385	17.03	277	40.30
BOD ₅ (mgO ₂ /L)	390	348	10.77	318	18.46	240	38.46
TDS (mg/L)	547	468	14.44	460	15.90	373	31.81
Oil & Grease (mg/L)	254	225.3	11.29	192	24.41	126.5	50.19

%R = Percentage of removal, Con. = concentration

Degreasing / settling as pretreatment followed by CWHF

The settling time of the greywater was 3.0 hr. Results in Table 4 showed that the settling process achieved reasonable removal of TSS, COD, BOD₅ and oil & grease at the rate of 64%, 30%, 28% and 37%, respectively.

The effluent was subjected to CWHF for 24 hr. The results obtained showed remarkable removal reached 81%, 56%, 49% and 73% for the TSS, COD, BOD₅ and oil & grease, respectively, (Table 4). It can be concluded that the COD, BOD₅ and oil & grease, except TSS are still over the permissible level of 2nd group, "secondary wastewater treatment" for irrigation reuse according to Egyptian Guideline⁽²¹⁾.

Degreasing / settling as pretreatment followed by the hybrid system (CWHF and CWVF)

The settling time of the greywater was 3.0 hr and the effluent was subjected to the constructed wetland for 24 hr. The results obtained showed remarkable removal reached 87%, 83%, 88% and 92% for the TSS, COD, BOD₅ and oil & grease, respectively, (Table 4). However, the characteristics of the TSS, COD, BOD₅ and Oil & Grease were 16.17, 77.5, 39.83 and 9.76 mg/l, respectively. It is worth noticing that the characteristics of this final effluent are within the permissible level of 2nd group, "secondary wastewater treatment" for irrigation reuse according to Egyptian Guideline⁽²¹⁾.

TABLE 4. Main characteristics of raw greywater, effluent of degreasing/settling tank, effluent of horizontal wetland, and the effluent of the vertical wetland as well as removal efficiency of each treatment step. [The standard division is given between brackets].

Parameter	TSS	COD	BOD ₅	SAR	TP	NO ₃	Oil & Grease	TKN	Number of cells or eggs of Nematoda	<i>E.coli</i> count
Unit	mg/l	mg/l	mg/l	%	mg/l	mg/l	mg/l	mg/l	(Count/l)	(100/ml)
Raw Greywater average	126.67 (±20)	470.17 (±44)	346.17 (±44)	20.87 (±1.8)	9.91 (±1.1)	2.67 (±0.20)	124.83 (±23.2)	45 (±5.9)	---	---
Settling effluent	44.92 (±16)	328.79 (±31)	247.93 (±30)	19.69 (±1.8)	7.69 (±0.8)	2.42 (±0.23)	79.09 (±17.7)	38.33 (±5.6)	---	---
Settling (R %)	64.54%	30.07%	28.38%	5.65%	22.40%	9.36%	36.64%	14.82%	---	---
Horizontal flow wetland (effluent)	24.45 (±11)	207.46 (±26.7)	175.58 (±49.6)	14.91 (±2.4)	3.19 (±0.4)	1.61 (±0.26)	34.10 (±7.4)	26.64 (±5.4)	1	<100
Horizontal wetland (R %)*	80.70%	55.87%	49.28%	28.56%	67.81%	39.70%	72.68%	40.80%	---	---
Vertical wetland (effluent)	16.17 (±6)	77.5 (±45)	39.83 (±8)	13.59 (±4.2)	0.93 (±0.08)	1.7 (±0.21)	9.76 (±1.48)	18.93 (±5.0)	1	<100
Vertical wetland (R %)	33.86%	62.64%	77.31%	8.85%	70.85%	5.59%	71.38%	28.94%	---	---
Overall R %***	87.23%	83.52%	88.49%	34.88%	90.61%	36.33%	92.18%	57.93%	---	---
Permissible limits 2 nd group for (secondary treatment)**	40	80	40	20	---	---	10	---	1	1000

%R = Percentage of removal, *Horizontal wetland (R %) = Percentage of total removal by degreasing/settling for 3.0 hr followed by horizontal constructed wetland, ***Overall % R = Percentage of total removal by degreasing/settling for 3.0 hr followed by hybrid constructed wetland, **Egyptian Guideline = Egyptian code no. 501, 2005 for the reuse of treated wastewater in agriculture: Ministry of Housing, Utilities and New Communities.

Conclusion and Economy of The System

- The results of pilot plant indicated good quality of the treated final effluent.
- The advantage of CW_s is that they are environmentally friendly, cost effective.
- CW for 24 hr could achieve much higher removal rate of the pollution parameters. The characteristics of the final effluent could cope with the permissible level of 2nd group “secondary wastewater treatment” for irrigation reuse according to Egyptian Guideline.

Recommendations

- Separation of municipal wastewater can be implemented in the remote and decentralized areas.

- From the available data it can be recommended that the use of CW as a post treatment step after a settling tank is a promising technology for greywater reclamation and reuse.
- The CW requires large area of land for construction. Therefore, such system can be implemented in the remote and decentralized areas of Egypt as well as the Middle East and North African countries “MENA”.

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كفاءة معالجة المياه الرمادية عن طريق استخدام أحواض إزالة الدهون / الترسيب متبوعة بالأراضي الرطبة المزدوجة

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الدراسة الحالية تتعامل مع المياه الرمادية الخام . تهدف الدراسة الى تقديم تحريات
فى معالجة المياه الرمادية وإعادة استخدامها. فحصت خواص المياه الرمادية اولاً
من خلال معرفة افضل زمن فى أحواض إزالة الدهون / الترسيب. ومن ثم اختبار
امكانية وكفاءة الأراضي الرطبة المزدوجة فى إزالة الملوثات. الطرق التجريبية
والمعملية تضمنت الوصول الى المحددات المطلوبة والمسموح بها فى
إعادة استخدام المياه طبقاً للكود المصرى، هذا
وقد وصل معدل الإزالة النهائى للنظام الى 87% ،
83% ، 88% ، 91% ، 36% ، 92% ، 58% لكل من TSS, COD
BOD₅, TP, NO₃, oil & grease and TKN على الترتيب كما
وصلت بكتريا اى-كوليا وعدد بيوض
النيماتودا الى 100/ml و Egg/1 على الترتيب .