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Anaerobic/aerobic integration via UASB/enhanced aeration for greywater treatment and unrestricted reuse

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Abstract

The aim of the present study is to achieve an efficient treatment of greywater for reuse in food crops' irrigation. For this purpose, anaerobic followed by enhanced aerobic treatment system was examined via both bench scale and pilot plant. The greywater was separated and collected from the source. The examined systems consisted of Up flow Anaerobic Sludge Blanket (UASB) followed by anaerobic aeration enhanced by Effective Microorganism (EM). The characteristics of the raw greywater were within a high strength level due to the presence of detergents, phosphates, oil and grease. The BOD_5/COD was 0.75, showing that biological treatment to this greywater could be achieved. Treatment with UASB showed high elimination of oil & grease, BOD_5, COD, total phosphates, and TKN in the range of 60 to 84%. However, TSS and ammonia were poorly removed. UASB effluent was further aerobically treated in a continuous aerated system where the predetermined optimum EM dose was added. Both aeration time and EM dose were previously examined to reach the optimum. Anaerobic/aerobic pilot plant in the continuing treatment was evaluated, where the final treated effluent successfully reached the permissible limits for unrestricted reuse according to the international regulation, namely FAO, WHO, US EPA and Egypt.

Key words: alternative water resources, anaerobic and aerobic processes, effective microorganism (EM), greywater treatment, unrestricted treated wastewater reuse

INTRODUCTION

Greywater is defined as the wastewater that is produced from bathroom sinks, kitchen sinks, baths, showers and laundries (Couto *et al.* 2015). It makes up between 70 and 73% of the municipal wastewater. It has the lowest amount of organic contaminants and few pathogens or none at all compared to municipal and/or domestic wastewater. Therefore, greywater can be treated efficiently by using simple technologies for the purpose of reuse (Boyjoo *et al.* 2013; Parameshwara *et al.* 2016).

Reuse of treated greywater for non-potable purposes could be an important choice as an alternative resource of water in arid and semi-arid districts. There are different designed systems for treating of greywater varied from simple to advanced technology, depending on the required quality of water reuse in different sectors. Surfactants, salts, food particles, total suspended solids, microorganisms, oil and grease are the most common contaminants in greywater (Abdel-Shafy & Mansour 2013). Characteristics of greywater are variable according to lifestyle, cultural and social behavior of the consumer (Hourlier *et al.* 2010).

Reuse of treated greywater should be a part of integrated actions to reduce fresh water consumption for irrigation. It represents an adequate and an alternative source of non-potable purposes (Abdel-Shafy & Mansour 2013; Galvis *et al.* 2014). This treated water can reduce between 29 and 47% of household freshwater consumption, which leads not only to decrease supplies of potable water but also to increase economic benefits (Naylor *et al.* 2012). Treated greywater is efficiently used for several purposes, including gardening, toilet flushing, laundry, floor washing, firefighting ….etc. (Al-Sa'eda *et al.* 2009; Santos *et al.* 2012). Toilet flushing can be implemented easily in hotels, resorts and remote areas in order to save a great amount of water consumption. Till the present time, most greywater recycling has been carried out in decentralized or on-site systems. Little attention, worldwide; is given to separating and treating greywater. It is reused at small-scale, mostly within the community, household, or a neighborhood (Naylor *et al.* 2012; Abdel-Shafy *et al.* 2014a, 2014b). Other investigators have reported that reuse of greywater has certain disadvantages, due to the use of sophisticated equipment units for treatment (Kanawade 2015; Abdel-Shafy & Abdel-Shafy 2017).

Therefore, it is important to develop simple techniques for the treatment of greywater. This could be achieved by employing simple, efficient, and low cost systems in terms of operation and maintenance (Abdel-Shafy *et al.* 2015). For example, high rate anaerobic treatment is efficient as an on-site system which performs even in countries with low-temperature (Abdel-Shafy & El-Khateeb 2013).

The up-flow anaerobic sludge blanket (UASB) reactor is the most applicable in anaerobic treatment of greywater. The UASB gives efficient elimination of the organic loads (i.e. BOD_5 and COD, oil and grease). It also reduces the concentration of nitrogen and phosphate compounds (Abdel-Shafy *et al.* 2015). In addition, organic degradation of the sludge can be achieved by the UASB while producing a biogas as a source of green energy. However, it is less efficient in elimination of total suspended solids (TSS), ammonia, and sulfide (Abdel-Shafy & Mansour 2016).

On the other hand, aeration methods have proved to be an efficient method for removing different contaminants from wastewater. Such aeration processes depend mainly on supplying air to the treatment system. Other technologies, including membrane bioreactors, high-rate aerobic systems, aerobic filters, fluidized beds, rotating biological contactors, and constructed wetlands were also used for greywater treatment (Al-Sa'eda *et al.* 2009; Masi *et al.* 2010; Abdel-Shafy & Al-Sulaiman 2014a, 2014b).

Meanwhile, effective microorganisms (EM's) are known as a mixture of several groups of organisms that have a reviving action on humans, animals, and the natural environment. This mixture has also been described as a coexisting multi-culture of both anaerobic and aerobic useful microorganisms (Shalaby 2011; Abdel-Shafy & Mansour 2016). The EM is composed of a selected, formulated bacterial consortium consisting of isolated bacterial strains. It acts in a synergistic way and it is easily capable of degrading almost all the associated organic compounds present in municipal wastewater. Meanwhile, this consortium can effectively reduce the pollution load of the sewage water up to the desired discharge limits. The most common microorganisms involved in this EM are: photosynthetic bacteria (*Rhodo Pseudo monaspalustrus, Rhodo Bacterspaeroides*), lactic acid bacteria (*Lactobacillus Plantarum, Lactobacillus Casei, streptoccuslactis*), actino mycetes (*Streptomyces Albus, Streptomyces griseus),* and yeasts (*saccharomyces cerevisiae, candida utilis*). The main reason for using EM in wastewater treatment is the presence of these different microorganism species all together. EM also includes different organic acids related to the presence of lactic acid bacteria that secrete enzymes, metallic chelates, and antioxidants (Abdel-Shafy & Mansour 2016). Meanwhile, EM helps in creating an anti-oxidant environment that improves the solid-liquid separation, as the major objective for cleaning water. One of the main benefits of using EM is the effective decrease in the sludge volume. The EM organisms could use wastewater organic matter for growth and reproduction, and are also able to decay it into methane (CH_4) or carbon dioxide (CO_2) (Shalaby 2011; Abdel-Shafy *et al.* 2013). Several investigators used EMs for the treatment of either municipal and/or organic industrial wastewaters (Abdel-Shafy & Mansour 2016, 2017). The optimal physical conditions for formulating EM were determined by culturing microbial consortia at various concentrations of molasses, pH of 6.5–8, and a temperature of 28 and 37 °C (Abdel-Shafy *et al.* 2013; Abdel-Shafy & Mansour 2016).

The aim of the present study is to achieve an efficient treatment of greywater for the purpose of reuse. For this purpose, an integration of anaerobic and enhanced aerobic systems was used to reach unrestricted water reuse. Real greywater was separated and treated in this study. The anaerobic process, namely UASB, was constructed and evaluated, followed by aerobic treatment consisting of aeration, which was loaded with effective microorganisms (EM). The effect of different aeration times and variable EM doses were studied. The optimum conditions were investigated in a continuous flow pilot-plant. The final treated effluents were evaluated according to the characteristics of non-potable unrestricted water reuse.

MATERIALS AND METHODS

All the experimental studies were carried out using real greywater in a pilot plant constructed in Training Demonstration Center (TDC), National Research Center (NRC), Cairo, Egypt.

Source of greywater

Real domestic wastewater was separated from one house into three different segregations namely: grey (G), black (B), and yellow (Y) waters. Each wastewater was connected to an individual separated manhole. This study was conducted in the experimental land area of the TDC site at the NRC. The source of the collected wastewater is from five apartments with an average of 4 people each (i.e. 20 P.E.). The present investigation is concerned with the collected greywater (G) in the TDC, which included the wastewater outlet from hand washbasins, showers, baths, kitchen sinks, dishwashers, and washing machines. In the present study all physical, chemical, and biological characteristics of the raw greywater before and after treatment were determined according to APHA (2012).

EM isolation, characterization and formulation

Effective microorganisms (EMs) were purchased in a liquid phase from the Egyptian Ministry of Agriculture of Egypt (EMA). EMs isolation was conducted by the MAE. The obtained colonies were sub-cultured to obtain a pure culture. This isolated culture was identified by several morphological and biochemical studies. Biochemical tests, including catalase test, oxidase test, IMViC test, sugar fermentation tests, triple sugar iron test, urease test and hydrolysis tests were studied by the MAE. The formulation of EM was also investigated by the MAE, where the isolated microorganisms were cultured together in a molasses medium at different concentrations of molasses, pH, and temperature.

Sequence treatment process

Greywater was pumped from the manhole into the UASB for anaerobic treatment. Two sequence processes were investigated in the present study (Figure 1). The effluent from the UASB was directed by gravity to the aerobic tank, which was under continuous aeration using two aeration devices. EM was added to the aeration tank at the predetermined optimum dose to enhance the efficiency of treatment. The physical and chemical characteristics of the effluent of each treatment step were determined and evaluated according to the permissible limits for unrestricted reuse.

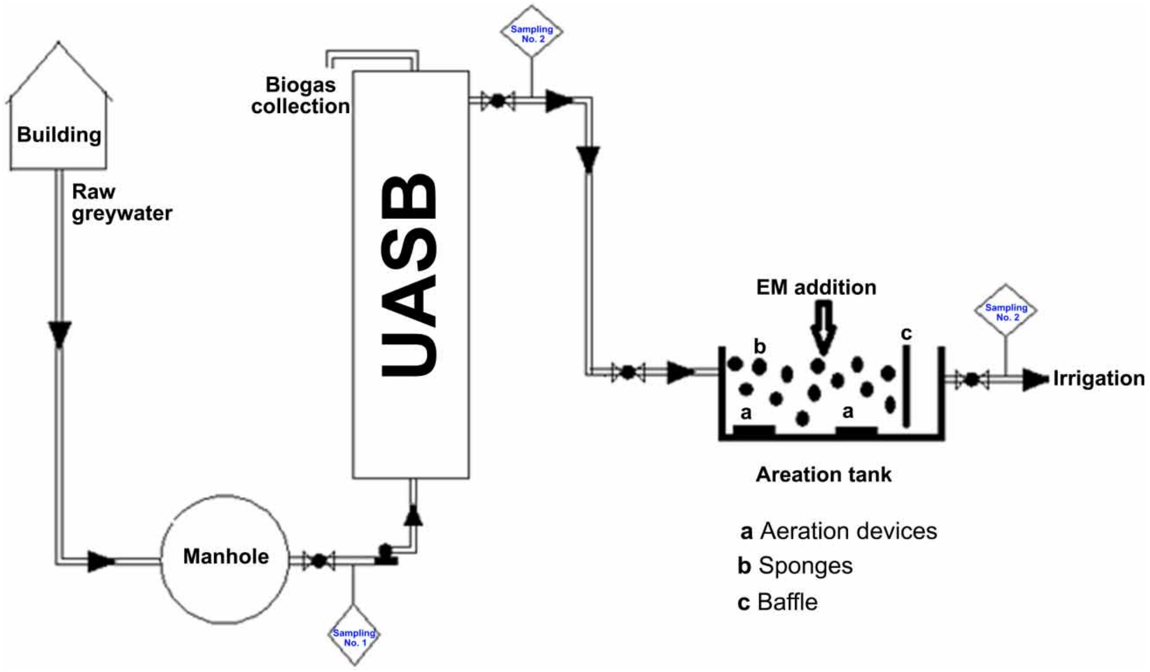

Figure 1 | Schematic diagram of the pilot plant system where (a) is the aeration devices, (b) is the sponges and (c) is the baffle.

Bench scale study

By using the jar test apparatus at room temperature, the UASB effluents were sampled and subjected to the following studies for the purpose of determining the optimum operating conditions of the aeration tank:

*_**Aeration times**_**:** Effect of different aeration times, namely 15, 30, 60, 90 or 120 min, were investigated in terms of the chemical and physical characteristics of greywater.

*_**Effect of EM doses**_: Different doses of EM ranging from 0.5 to 1.5 mL/L were examined at the predetermined optimum aeration time.

Continuous flow pilot plant for greywater treatment

UASB reactor

One UASB reactor was designed and installed in the TDC site for the treatment of greywater. The reactor was made of nontransparent PVC. The UASB dimensions and operation conditions were previously described by Abdel-Shafy *et al.* (2015) as follows:

Outer height: 3.5 m
The internal effective wastewater volume: 250 litters
Material of the piping system: PVC
Releasing and holding greywater: by valves
Internal UASB diameter: 0.4 m
Total sludge content: 22/L
Wastewater hydraulic retention time (HRT): 6 hours*

*As calculated according to the mathematical equation described by Crites & Tchobanoglous (1998).

BOD_5 and COD organic loading rates (OLR) were: 1.103 kg BOD_5/m^3/day and 1.93 kg COD/m^3/day.

The hydraulic loading rate (HLR): 1–4 m^3/ m^3/day.

Operation of UASB

Before operating the UASB, clean tap water was introduced from the bottom of the UASB reactor to evacuate any gathered solid wastes. Greywater was pumped from the manhole to feed the UASB four times/day at equal intervals. Greywater was supplied to the UASB (Figure 1) from the bottom through a pipe of 50 mm in diameter, and was spread over a cross-section of the reactor using a perforated Plexiglas plate that was placed at 40 cm above the feed tube. Four sample outlets along the reactor were placed at 1.00 m distance from one another in the digestion zone. Another two outlets were placed as follows: one was 0.30 m from the top of the reactor and another was placed at 0.10 m from the bottom, where the latter was used to remove the solids. The hydraulic retention time (HRT) of the UASB was allowed to reach the reactor steady state. The organic loading rate (OLR) in the reactor was maintained at 1.1 kg $BOD_5/m^3/d$ and 1.93 kg $COD/m^3/d$. Continually, the performance of the reactor was recorded daily through 24 h, where the composite samples were taken from the inlet and outlet ports of the reactor.

Aeration process

The effluent of the UASB reactor was directed to a rectangular aeration tank. The dimensions of the aeration tank were 1.15 m (L) × 1.00 m (w) × 0.55 m (D) with a total capacity of 350 liters (Figure 1). It consisted of two baffled separated chambers. The dimensions of the main effective chamber is 0.85 m (L) × 1.00 m (W) × 0.55 m (D) with a volume of 258.7 L. The other chamber is small, with dimensions of 0.30 m (L) × 1.00 m (W) × 0.55 m (D), and a total volume of 91.3 L. The main effective chamber contained small cubic sponges that were randomly spread, occupying about 38% of the total wastewater volume. The sponges' specifications are: 1.8 cm (L) × 1.8 cm (W) × 1.8 cm (D), surface area 4.78 m^2/m, and total weight 10 kg/m^3. The small chamber was designed to receive the aerated wastewater from beneath the baffle in order to avoid the presence of any sponge cubes.

Greywater in the effective chamber was subjected to continuous aeration. In addition, the predetermined optimum dose of EM was added to examine the treatment efficiency. The outlet of the treated wastewater was simultaneously directed to the small second chamber as the final treated effluent. Two small aerators at 116 psi pressure capacity were immersed at the bottom of the aeration tank as a source of continuous air supply.

RESULTS AND DISCUSSION

Raw greywater

A weekly sampling program was designed to collect the raw greywater for the determination of the physical and chemical characteristics. The gained results (Table 1) indicate that the value of pH, EC, total dissolved solids (TDS), TSS, COD, BOD_5, ammonia-N, total phosphates (T.P.), oil and grease were 7.03, 735, 460, 155, 505, 380, 9, 12 and 290 mg/L, respectively. The nitrates and total Kjeldahl nitrogen were 0.7, and 32.5 mg/L, respectively. These results presented the average level of a high strength greywater. Usually, such greywater also contains high concentrations of detergents as well as slowly biodegradable oil & grease that is usually generated from the kitchen outlet. The presence of T.P. is related mainly to the detergents that are consumed daily in the greywater.

The average ratio of BOD_5/COD in the raw greywater ranged from 0.74 to 0.76 at an average of 0.75, confirming the possibility of biological treatment. Metcalf & Eddy (2003) reported the average ratio of $COD/NH_3/TP$ is typically at 100/5/1 for domestic wastewater. Kargi & Uygur (2003)

Table 1 | Chemical and physical characteristics of the raw greywater (six months' duration)

Parameter	Unit	N.	Min value ± STDEV	Max value ± STDEV	Average ± STDEV
pH	–	40	6.0 ± 0.12	8.06 ± 0.16	7.03 ± 0.14
EC	ms/cm	40	550.0 ± 11	920 ± 18.4	735 ± 14.7
Temperature	°C	40	25.1 ± 0.5	29 ± 0.58	27.05 ± 0.54
D.O.	mg/L	40	0.2 ± 0.004	0.5 ± 0.01	0.3 ± 0.006
TDS	mg/L	40	320 ± 6.4	600 ± 12	460 ± 9.2
TSS	mg/L	40	140 ± 2.8	170 ± 3.4	155 ± 3.1
COD	mg/L	40	460 ± 9.2	550 ± 11	505 ± 10.1
BOD_5	mg/L	40	340 ± 6.8	420 ± 8.4	380 ± 7.6
BOD_5/COD	Ratio	40	0.74 ± 0.01	0.76 ± 0.01	0.75 ± 0.015
Ca	mg/L	40	155 ± 3.1	450 ± 9	302.5 ± 6.05
Mg	mg/L	40	85 ± 1.7	150 ± 3	235 ± 4.7
Na	mg/L	40	270 ± 5.4	430 ± 8.6	350 ± 7
T. P.	mg/L	40	9 ± 0.18	15 ± 0.3	12 ± 0.24
Nitrates	mg/L	40	0.5 ± 0.01	0.9 ± 0.018	0.7 ± 0.014
Nitrites	mg/L	40	ND	ND	ND
Ammonia-N	mg/L	40	8 ± 0.16	10 ± 0.2	9 ± 0.18
TKN	mg/L	40	30 ± 0.6	35 ± 0.7	32.5 ± 0.65
Oil & grease	mg/L	40	280 ± 5.6	300 ± 6	290 ± 5.8
SAR_{adj}	%	40	25 ± 0.5	35 ± 0.7	30 ± 0.6
E. Coli	Number per 100 ml	ND	ND	ND	ND
Intestinal nematodes	Number per L	ND	ND	ND	ND
Total coliforms	Number per 100 ml	ND	ND	ND	ND

N, Number of samples; **EC**, electrical conductivity; **D.O.**, dissolved oxygen concentration; **TDS**, total dissolved solids; **TSS**, total suspended solids; **COD**, chemical oxygen demand; **BOD**, biological oxygen demand; **T.P.**, total phosphates; **TKN**, total Kjeldahl nitrogen; **SAR_{adj}**, adjusted sodium absorption ratio; **ND**, not detected; **STDEV,** standard deviation.

calculated the optimum ratio of COD/NH_3/TP for maximum nutrient removal in the activated sludge process, with a five-step sequencing batch reactor (SBR) at 145/5.87/1. On the other hand, Jefferson *et al.* (2000) measured the COD/NH_3/TP ratio at 1030/2.7/1 for greywater, pointing out the micronutrient limits. In the present study, the COD/NH_3/TP ratio in the raw greywater was 56.1/1.0/1.3, pointing out the high level of phosphates. Previously, the raw greywater characteristics were studied by Abdel-Shafy *et al.* (2009), and it was recommended that raw greywater could only be reused for irrigating woody lumber trees. However, treatment of greywater using several simple technologies was successfully achieved by several investigators (Kargi & Uygur 2003; Masi *et al.* 2010; Abdel-Shafy & Mansour 2017).

UASB pilot plant reactor for raw greywater treatment

The characteristics of the UASB treated effluent are shown in Table 2. The UASB treatment showed reasonably efficient removal of oil & grease, total phosphates (T.P.), and TKN at the rate of 84.6, 81.3 and 72.2%, respectively. The recorded decrease of these parameters was from 286.5 to 43.5 mg/L for oil & grease, 11.5 to 2.15 mg/L for T.P., and 31.25 to 8.7 mg/L for TKN. Such efficient removal is due to the anaerobic nature of UASB treatment, which is able to achieve valuable degradation of organic loads that were converted to biogas. The present findings are in good agreement with that reported by Abdel-Shafy *et al.* (2009) and Kanawade (2015). It well documented that oil & grease are usually

Table 2 | Effect of anaerobic treatment of greywater on the chemical and physical characteristics using UASB

Parameters	Unit	N	Raw greywater (average)	UASB effluent (average)	
				R. Con.	% R
TSS	mg/L	5	149 ± 3	118.46 ± 2.4	20.5
COD	mg/L	5	498.5 ± 10	197.41 ± 4	60.4
BOD_5	mg/L	5	372.5 ± 7.5	120.05 ± 2.4	67.8
BOD_5/COD	Ratio	5	0.75 ± 0.04	0.61 ± 0.01	–
Oil & grease	mg/L	5	286.5 ± 5.7	43.55 ± 0.87	84.6
T.P.	mg/L	5	11.5 ± 0.23	2.15 ± 0.04	81.3
Ammonia-N	mg/L	5	8.75 ± 0.18	7.07 ± 0.14	19.2
TKN	mg/L	5	31.25 ± 0.61	8.7 ± 0.17	72.2

N, number of samples.

poorly removed by conventional wastewater treatment methods (Jefferson *et al.* 2000; Metcalf & Eddy 2003). But in the present study, UASB was able to achieve high removal of oil & grease at the rate of 84.6%. Meanwhile, COD and BOD_5 removal decreased from 498.5 to 197.41, and from 372.5 to 120.05 mg/L, which correspond to a removal rate of 60.4 and 67.8%, respectively. The average ratio of BOD_5/COD in the UASB treated effluent became 0.61 (i.e. lower than 0.75 in the raw greywater). This decrease referred to the fact that the removal rate of the organic load as BOD_5 (67.8%) was slightly higher than that of the chemical load as COD (60.4%). However, the present BOD_5/COD ratio was still within the organic nature of this wastewater (i.e. suitable for biological treatment).

On the contrary, poor removal of both TSS and ammonium nitrogen reached the rates of 20.5 and 19.2%, respectively. The corresponding decrease was from 149 to 118.46 mg/l for TSS, and from 8.75 to 7.07 mg/L for ammonia-N (Table 2). The calculated COD/NH_3/TP in the present effluent was 91.8/3.3/1, which correlated to the values reported by Metcalf & Eddy (2003). This indicates that the UASB influent can be further biologically treated.

Although UASB could remove oil & grease, BOD_5 and TP, it was still poor in the removal of TSS and ammonia-N. Therefore, it was necessary to employ further treatment in the aerobic system to achieve further removal of the concerned pollutants.

Aerobic treatment of greywater by aeration

Effect of variable aeration times for greywater treatment

The effect of variable aeration times ranging from 15 to 120 minutes is given in Table 3. These results pointed out that the longer the aeration time, the better the removal of pollutants. This is mainly due to the enhancement of the existing bacteria to consume the nutrient elements from the greywater. At 120 min. aeration time, the characteristics of the aerated wastewater were 37.14, 121.03, 75.93 and 5.14 mg/L for TSS, COD, BOD_5, and oil & grease, respectively. The highest removal rates were achieved for oil & grease and TSS at 88.5 and 68.8% respectively. On the contrary, removal rates of COD and BOD_5 were only 39 and 37%, respectively. However, the BOD_5/COD ratio slightly increased from 0.62 to 0.63 by increasing the aeration time to more than 60 minutes (Table 3). Unexpectedly, the characteristics of final aerated effluent with regard to BOD_5 and COD did not cope with the permissible limits for unrestricted reuse according to different international regulations (Table 4) by FAO (2003), US EPA (2012), WHO (2006), and Egyptian regulation (2013). Therefore, it was decided to add effective microorganisms (EM) to the aeration system in the pilot plant for the purpose of improving the biological treatment.

Table 3 | The effect of aeration at different times on the chemical and physical characteristics of UASB effluent

				Aerating time									
				15 min		**30 min**		**60 min**		**90 min**		**120 min**	
Parameters	**Unit**	**N**	**UASB effluent (average)**	**R. Con.**	**% R**	**R. Con.**	**% R**	**R. Con.**	**% R**	**R. Con.**	**% R**	**R. Con.**	**% R**
TSS	mg/L	5	119.03 ± 2.4	113.43 ± 2.3	4.7	106.17 ± 2.1	10.8	91.06 ± 1.8	23.5	63.32 ± 1.3	46.8	37.14 ± 0.7	68.8
COD	mg/L	5	198.41 ± 4	178.37 ± 3.6	10.1	167.85 ± 3.4	15.4	146.82 ± 3	26	133.93 ± 2.7	32.5	121.03 ± 3.6	39.0
BOD_5	mg/L	5	120.53 ± 2.4	110.89 ± 2.2	8.0	100.04 ± 2	17	92.81 ± 1.8	23	84.37 ± 1.7	30	75.93 ± 1.5	37.0
BOD_5/COD	Ratio	5	–	0.62 ± 0.01	–	0.60 ± 0.012	–	0.63 ± 0.013	–	0.63 ± 0.014	–	0.63 ± 0.015	–
Oil & Grease	mg/L	5	44.68 ± 0.9	36.01 ± 0.7	19.4	25.91 ± 0.5	42	18.32 ± 0.4	59	10.72 ± 0.2	76	5.14 ± 0.1	88.5

N, Number of samples; **% R,** Percentage of removal; **R. Con.**, residual concentration.

Table 4 | Guidelines and regulations for treated wastewater reuse in food crop irrigation

Parameter	Unit	WHO	FAO	US – EPA	Egypt
EC	μs/cm	–	<700	≤700	≤700
pH	–	–	6.5–8.4	6–9	6.5–8.5
TSS	mg/L	–	10	–	≤15
TDS	mg/L	–	<450	–	–
BOD	mg/L	–	10	≤ 10	≤10
COD	mg/L	–	–	–	≤10
T-P	mg/L	–	–	–	≤2
T-N	mg/L	–	–	–	≤3.5
Nitrate (NO_3-N)	mg/L	–	<5	–	–
Ammonia-N	mg/L	–	–	–	0.5
Oil & grease		–	–	–	5
Total coliform	Number per 100 ml	–	–	–	–
Fecal coliform	Number per 100 ml	≤1,000	5	ND	ND
E. coli	Number per 100 ml	≤1,000	–	–	–
Intestinal nematodes	Number per L	≤1	–	–	ND

ND, not detected.

Effect of different EM doses on greywater treatment

For the determination of the optimum EM dose, the jar test was employed at different EM doses varying from 0.5 ml/L to 1.5 ml/L. UASB treated effluent aerated at the predetermined optimum time (120 min) was used in the present investigation. The results (Table 5) show that increasing removal rates were associated with increasing EM doses. The optimum determined EM dose was 1.5 ml/L, at which the removal rate reached 90, 95.5, 94, and 94% for TSS, COD, BOD_5, and oil & grease, respectively (Table 5). Meanwhile, the BOD_5/COD ratio was slightly increased from 0.57 to 0.81. At this optimum dose, the characteristics of the treated effluent were 11.88, 8.91, 7.22 and 2.65 mg/L for TSS, COD, BOD_5 and oil & grease, respectively, where the corresponding removal rates ranged from 90 to 95.5% (Table 5). This achievement can be attributed to the enhancement of the aeration system in the presence of the EM.

The use of EM in the treatment of wastewater simulates the role of biological treatment efficiently. In such a system, bacteria and other microorganisms are used to remove organic pollutants and other impurities from wastewater by digesting and removing them. The EM bacteria consume and digest such organic pollutants through metabolism. The organic pollutants are changed into cellular masses that are no longer in solution, where they settle down to the bottom of a container or settling tank (Abdel-Shafy *et al.* 2014a, 2014b; Rashed & Massoud 2015).

Anaerobic/aerobic integrated continuous system for greywater treatment

The effluent of the UASB pilot plant was directed to the aeration tank under continuous aeration as well as the addition of 1.5 ml/L EM to enhance the biological treatment. The results (Table 6) showed that aeration with the addition of EM achieved remarkable efficiency in greywater treatment. The overall removal of the final treated wastewater reached 92.6, 98.4, 98.3, 99.2, 90.5, 95.3, and 94.0% for TSS, COD, BOD_5, oil & grease, TP, ammonia-N and TKN, respectively (Table 6). The residual concentrations were 11, 8.0, 6.6, 2.3, 1.04, 0.4, and 1.8 mg/L, respectively (Figure 2). The characteristics of this final treated effluent could perfectly cope with different international

Table 5 | Effect of EM doses (at 120 min aeration) on the chemical and physical characteristics of UASB effluent

				EM doses									
				0.50 (ml/L)		**0.70 (ml/L)**		**0.90 (ml/L)**		**1.20 (ml/L)**		**1.50 (ml/L)**	
Parameters	**Unit**	**N**	**UASB effluent (average)**	**R. Con.**	**%R**	**R. Con.**	**%R**	**R. Con.**	**%R**	**R. Con.**	**%R**	**R. Con.**	**%R**
TSS	mg/L	5	118.75 ± 2.4	35.63 ± 0.71	70	28.5 ± 0.57	76	22.56 ± 0.45	81.0	13.54 ± 0.27	88.6	11.88 ± 0.24	90
COD	mg/L	5	197.91 ± 4	50.47 ± 1	74.5	38.80 ± 0.78	80.4	22.76 ± 0.46	88.5	14.87 ± 0.3	92.5	8.91 ± 0.18	95.5
BOD_5	mg/L	5	120.29 ± 2.4	28.87 ± 0.6	76	21.46 ± 0.43	82	15.04 ± 0.3	87.5	12.03 ± 0.24	90	7.22 ± 0.14	94
BOD_5/COD	Ratio	–	–	0.57 ± 0.01	–	0.55 ± 0.01	–	0.66 ± 0.013	–	0.80 ± 0.016	–	0.81 ± 0.016	–
Oil & grease	mg/L	5	44.12 ± 0.88	4.95 ± 0.1	88.8	4.37 ± 0.08	90.1	3.53 ± 0.07	92.0	3.04 ± 0.06	93.1	2.65 ± 0.05	94

N, Number of samples.

Table 6 | Pilot plant effluent characteristics in correlation with the criteria for wastewater reuse

				Effluent of UASB		Effluent after aeration (120 min) with EM (1.5 mL/L)		
Parameters	**Unit**	**N**	**Raw greywater (average)**	**R. Con.**	**% R**	**R. Con.**	**% R**	**Overall % R**
TSS	mg/L	20	149.5 ± 3	119.6 ± 2.4	20	11 ± 0.22	90.8	92.6
COD	mg/L	20	498.5 ± 10	199.4 ± 4	60	8.0 ± 0.16	96	98.4
BOD_5	mg/L	20	378 ± 7.56	121.0 ± 2.42	68	6.6 ± 0.13	94.5	98.3
Oil & grease	mg/L	20	286.5 ± 5.73	45.8 ± 1	84	2.3 ± 0.05	95	99.2
TP	mg/L	20	11 ± 0.22	2.3 ± 0.05	78.8	1.04 ± 0.02	55	90.5
Ammonia-N	mg/L	20	8.5 ± 0.17	7.3 ± 0.14	14.5	0.4 ± 0.008	94.5	95.3
TKN	mg/L	20	30 ± 0.6	7.7 ± 0.15	74.6	1.8 ± 0.04	76.8	94
E. coli count	Number per 100 ml	20	ND	ND	ND	ND	–	–
Intestinal nematodes	Number per L	20	ND	ND	ND	ND	–	–
Total coliforms	Number per 100 ml	20	ND	ND	ND	ND	–	–

ND, not detected.

regulations for treated wastewater for irrigating food crops by FAO (2003), WHO (2006), US EPA (2012), and Egyptian regulation (Amendment of law 48/1982, 2013) (Table 4).

Comparison between the present achievements in correlation with other investigators is given in Table 7. This comparison confirms that each reported system is uniquely efficient in removing the targeted pollutants. However, the present investigation was able to successfully reach the characteristics of the restricted water reuse by employing a simple, feasible, applicable, and efficient process.

DISCUSSIONS

The study showed that employing UASB could remove certain pollutants, namely oil & grease, total phosphates, TKN, BOD_5, and COD at rates ranging from 60 to 84%. However, UASB was less efficient at removing TSS and ammonia. This is mainly due to the anaerobic nature of this treatment system. The disadvantage of UASB is the release of methane, which leads to greenhouse gas emission and which is known for being a much greater threat than carbon dioxide to the environment. Nevertheless, the produced methane can be used as a source of energy for aeration. The physical and chemical characteristics of the UASB-treated effluent were far less qualified for reuse in crop irrigation (i.e. the characteristics did not reach the permissible limits for unrestricted water reuse). Based on this finding, it was essential to implement a further treatment using an aerobic system.

The aerobic system was continuously aerated and enhanced by the addition of EM at the predetermined optimum dose (1.5 ml/L) to increase the biodegradation effect. The study was carried out using a designed pilot plant as a continuous flow system (Figure 1). The physical, chemical and biological characteristics of the final treated effluent were evaluated and compared with the different international regulations for treated wastewater for irrigating food crops from the FAO (2003), US EPA (2012), WHO (2006), and Egyptian regulation (Amendment of law 48/1982 2013) (Table 4). It was, then confirmed that such final treated effluent could successfully cope with the characteristics of water for reuse for crop irrigation.

It is worth mentioning that using EM at the determined optimum dose will increase the total cost of the treatment process by 12.45%. However, the cost of EM can be reduced if it is purchased at the commercial price to reach the advantages of water recycling.

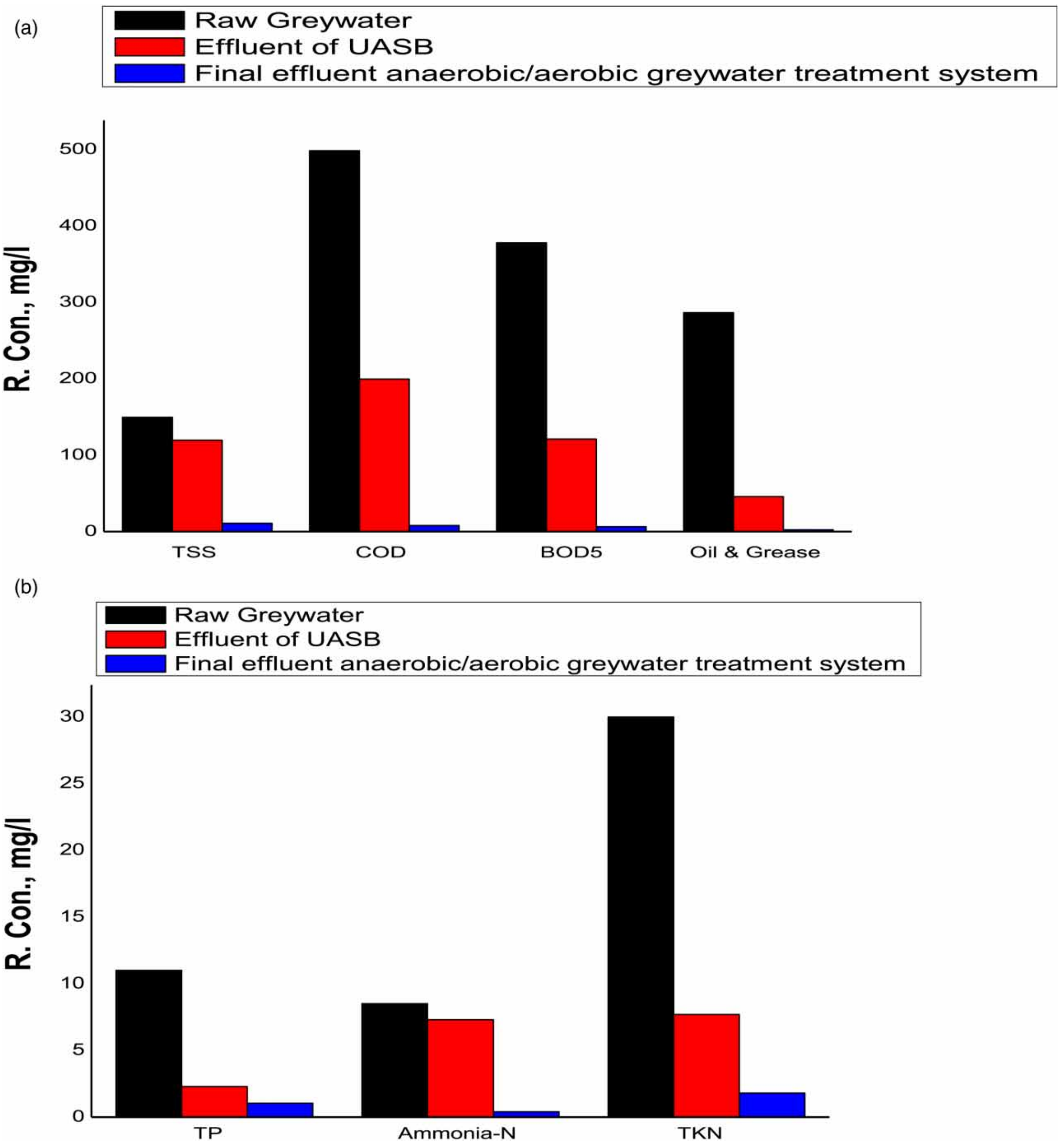

Figure 2 | Efficiency of anaerobic/aerobic greywater treatment. (a) Decrease of TSS, COD, BOD_5, and oil & grease; (b) decrease of T/P., ammonia –N, and TKN.

Table 7 | Comparison of the present study with some greywater treatment systems

Parameter	Filtration[a]	Wetlands[a]	SBR[a]	RBC[a]	MBR[a]	UASB[a]	Present study
TSS	53–93%	90–98%	–	9–12%	Up to 100%	–	92.6%
COD	37–94%	81–82%	90–98%	21–61%	86–99%	38–79%	98.4%
BOD_5	89–98%	Up to 99%	90–98%	27–53%	93–97%	Up to 67%	98.3%
Oil & Grease	Up to 97%	Up to 95.45	–	–	–	83.7%	99.2%
TP	Up to 100%	Up to 71%	–	–	Up to 19%	10 to 39%	90.5%
Ammonia-N	–	–	–	–	–		95.3%
TKN	–	–	–	–	–		94%

RBC, rotating biological contactors; **SBR**, sequencing batch reactor; **MBR**, membrane bioreactor.

[a] Oteng-Peprah *et al.* (2018).

CONCLUSIONS

Greywater could be reused for irrigating food crops if it receives satisfactory and efficient treatment using the present combined treatment system. The investigated anaerobic/aerobic system for the treatment of greywater is an effective, low cost, and feasible process. Aeration as an aerobic process can be enhanced by the addition of EM. The use of the EM consortia was efficient in enhancing the current conventional biological wastewater treatment processes. Thus, it can be concluded that this efficient, simple technique can be implemented successfully for the treatment of greywater to achieve water reuse for crop irrigation in areas that suffer from scarcity of water resources.

RECOMMENDATION

Greywater should be separated for treatment and reuse at least for non-potable purposes. Anaerobic/aerobic treatment technologies can be promising and feasible biological tools for treatment of greywater. The UASB reactor is an economic treatment technology that does not consume energy, instead it is an energy producer. Meanwhile, it proved to be effective in removing the organic pollution, including oil & grease, BOD, and COD. On the other hand, the aeration system could be improved by adding effective microorganisms that enhance the degradation process under continuous aeration. It is strongly recommended that the methane gas produced from the UASB is collected and used as a source of clean energy. This produced biogas can compensate for the cost consumed in the aeration process.

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