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Evaluation of the performance of the intermittent cycle extended aeration system in detergent removal from bathroom greywater

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ABSTRACT

On average, 67 % of household wastewater is made up of greywater, which includes wastewater produced in household other than toilets. There are different biological treatment processes for greywater treatment. One of these systems is the sequencing batch reactor (SBR), which has proven to be an effective way of treating wastewater. One of the amendments to the SBR process is the intermittent cycle extended aeration system (ICEAS). The purpose of this study was to investigate the performance of an advanced-SBR in the bathroom greywater (BGW) treatment. For this purpose, a rectangular SBR reactor (40×20×20 cm) with a working volume of 12 liters was developed and utilized. The primary microorganisms of this reactor were prepared from the active sludge return to the aeration pond of the Arak municipal wastewater treatment plant. The reactor was fed with the effluent from the initial settling ponds of the same treatment plant. After the system was set up and sufficient microorganisms were grown, the exploitation phase began with synthetic greywater. The experiments were carried out in three cycles of 4, 6 and 8 hours. The concentrations of linear alkyl benzene sulfonates (LAS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) at the inlet were 6.8 mg/L, 385 mg/L and 170 mg/L, and in the outlet, 0.95 mg/L, 19.25 mg/L and 8.5 mg/L, in a 8-hour cycle. Therefore, the removal efficiency of the system in 8 h cycle was 86 %, 93 % and 95 %, respectively.

1. Introduction

Household wastewater is recognized as one of the largest demands on water supply, thus its recycling and reuse will significantly reduce the amount of water consumed by households (Shamabadi et al. 2015; Moslemi Zadeh. 2013; Boyjoo et al. 2013). Household wastewater is divided into two categories: the first group is black water, which is defined as toilet waste, and the second is greywater, which includes other household wastewater sources such as laundry, bath, shower, kitchen and dishwasher (Al-Jayyousi. 2003). Greywater, as a diluted form of wastewater, contains an average of 67 % of wastewater (Chankya and Khuntia. 2014). Studies have shown that reuse of greywater can reduce the demand for fresh water by about 30-70 % (Wiltshire. 2005). In order to study the characteristics of greywater, it is important to consider their source. In the definition, greywater is divided into two groups of dark and light. Light greywater comes from bathroom/lavatory basins (sinks), showers, tubs and clothes washing machines, generally contain significantly less dissolved organic carbon, nitrogen and phosphorus than dark greywater. Dark greywater sources are non-laundry utility sinks and the kitchen, including sinks and dishwashers, typically contain more pathogens, chemicals, fats, oil and grease (Tsoumachidou et al. 2016; Katukiza et al. 2014; Penn et al. 2013).

The first synthetic detergent was made in 1916 in Germany and in the United States in 1946. The discovery of detergents was actually in order to meet the need for non-soap cleaners, which, unlike soap, don't combine with mineral salts of water don't create insoluble compounds. In 1960, the most surfactant reported in detergents was the alkyl benzene sulfonates (ABS) which increased wastewater problems due to biological degradation resistance. ABS has been replaced by carboxylic acids and linear alkyl benzene sulfonates (LAS) since 1967, which by 97-99 % degradation was identified as a biodegradable surfactant (Scott and Jones. 2002). LAS values in domestic wastewater were estimated to be about 3-21 mg/L and based on samples taken from municipal wastewater treatment plants, LAS values in effluent samples are about 0.071-0.71 mg/L (Torben. 2001). In general, the amount of LAS removal in wastewater treatment plants involves activated sludge system (ASS) about 85 % have been reported (Redisher. 1990).

One of the modifications on ASS is a sequencing batch reactor (SBR), which has proven to be an effective way on wastewater treatment. Between 1914 and 1920, several fill and empty systems, similar to SBR, were used. But the interest in SBR system re-emerged from the late 1950s and early 1960s with the development of new technologies (USEPA. 1999). The idea of utilization of this system was offered by Robert L. Irvine (USA, 1970s) (Metcaf and Eddy. 2003). The most important modifications on SBR system are biofilmic SBR, anaerobic SBR, and anaerobic-aerobic SBR. Intermittent cycle extended aeration system (ICEAS) is a superior technology than SBR process in, which the wastewater flows continuously into the basin. This means that the flow of input is not interrupted during the phases of the cycle. This system has three phases of aeration, settling and decanting in each cycle (Folke and Landner. 2000).

Shin et al. (1998) examined the performance of a SBR system in removing organic compounds and nitrogen from greywater. They considered the influent of 2 m^3/d and designed an equalization tank to store 2.5 m^3. They maintained dissolved oxygen (DO) and pH of 3.5 and 7.2 mg/L respectively. SBR performance was satisfactory in

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greywater purification, as the effluent was 20 mg/L, 5 mg/L and 0.5 mg/L of COD, BOD_5 and NH_3, respectively. In a study on removal efficiency of BOD_5, COD and detergents, Ehrampoush et al. (2007) concluded that artificial subsurface constructed wetland system has lower removal efficiency compared to the SBR system. Ghahfarrokhi et al. (2010) conducted a study on removal of detergents from hospital wastewaters using SBR method and indicated removal efficiencies of 94.54 %, 92.97 % and 84.99 % for BOD_5, COD and detergents, respectively. In a study by Pirsaheb et al. (2013) the average of LAS removal in an extended aeration process in winter and summer were 94.06 % and 99.23 %, respectively. In a study by Duarte et al. (2015) degradation of LAS in anaerobic SBR (ASBR) was evaluated. Degradation of the surfactant at the end of the operation was 87% and the removal of COD was 86 %. Eslami et al. (2015) conducted a study to evaluate the performance of an advanced-SBR in a treatment plant to remove organic materials and detergents. They achieved an efficiency of 92.92 %, 90.06 % and 81.6 % for BOD_5, COD and LAS, respectively.

The purpose of this study was to investigate the possibility of removing detergents and lowering the COD and BOD_5 from BGW by advanced-SBR (ICEAS) and determining the required time for each of the phases of the cycle in a specified flow rate.

2. Materials and methods
2.1. Experimental setup

The Schematic diagram of the ICEAS bioreactor is shown in Fig. 1. Experiments were carried out in a Plexiglas cube reactor with length, width and height of 40×20×20 cm and a working volume of 12 l (Fig. 2a). Raw wastewater in a 60 l feeding tank, continuously introduced to the reactor by a peristaltic pump. In order to provide sufficient air to microorganisms, an aeration pump with aeration rate of 5 l/m was used as well as 12 diffusers that placed at the bottom of the reactor. To ensure uniform distribution of air, especially at the low rate of aeration and in order to prevent sludge settlement without aeration, two mixers with 20 cm heights at 80 rpm were utilized (one near the bottom and the other at a height of 5 cm). It is to be noted that time of any phase and inflow level was set by an automatic the time control system. Each of the aeration, settling and decanting phases are shown in Fig. 2b, c and d, respectively.

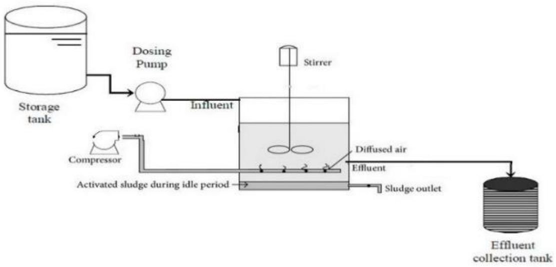


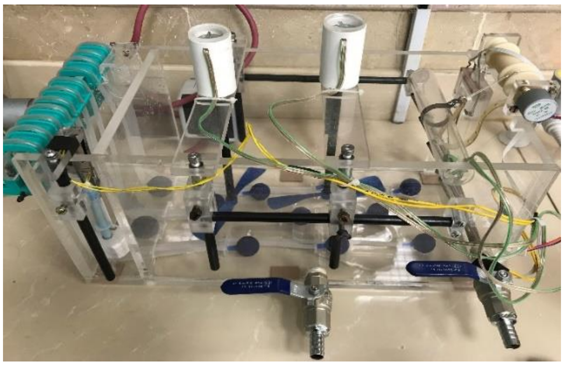
Fig. 1. Schematic diagram of the SBR system.

2.2. Synthetic bathroom greywater characteristics

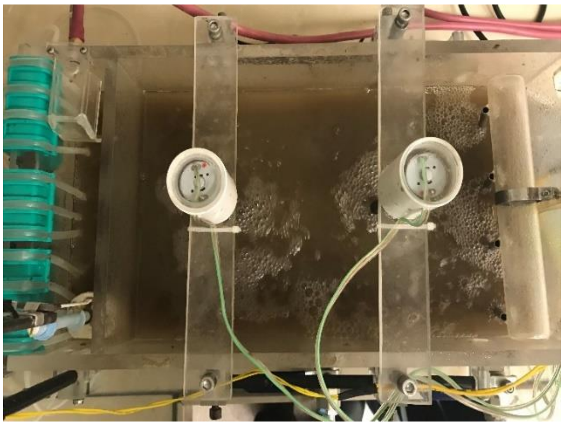
A synthetic feed solution was adapted from previous literature (McAdam et al. 2005) in order to produce an analogue greywater (Table 1). At all stages of loading, Na_2co_3 was used as the only source of carbon, urea and NH_4Cl as nitrogen sources and K_2HPO_4 as the phosphate source. The characteristics of the wastewater and the concentration range of the compounds contained therein are shown in Table 2. The apparent characteristic of wastewater before and after treatment is shown in Fig. 3. This can clearly be seen in Fig. 3 which show a photograph of treated wastewater (Fig. 3a) which has a very low turbidity compared to the raw wastewater (Fig. 3b).

2.3. Reactor start up and sludge specification

In order to start up SBR, the return activated sludge seed (sludge volume index (SVI): 280 mg/L, settled sludge volume (SSV); 760 mL/L) to aeration pond of the municipal wastewater treatment plant with an approximately volume of 4 L for a reactor containing 8 L of wastewater. By transferring this sludge to the reactor, the feeding stage started with the effluent from the initial sedimentation ponds (LAS: 4.3 mg/L, COD: 312 mg/L, BOD_5: 78 mg/L). The purpose of this stage was to adapt microorganisms that biological sludge was formed after 10 days and sticking to each other and settling well. The producing sludge was not removed, only a small amount at the top of clear liquid, was removed at the discharge stage. In addition, mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS) increased from low concentrations to 2714 mg/L and 2047 mg/L, respectively.

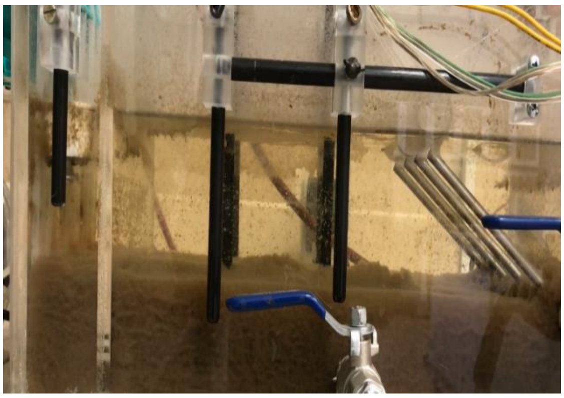


(a)



(b)

(c)



(d)

Fig. 2. a) SBR set up b) aeration c) settling d) decanting.

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Table 1. Composition of synthetic greywater (McAdam et al. 2005).

Ingredients	Amount per day per person	Feed concentration (mg/L) or (mL/L)
Tooth paste	1.5 gr	7.5
Shower gel	10 ml	0.05
Hand soap	0.7 gr	3.5
Domestic cleaner	60 ml	0.3
Oil/lotion	1 ml	0.005
Tertiary effluent	50 ml	0.25
Shampoo	5 ml	0.025
Bubble bath	25 ml	0.125
Urea	4 gr	20
Na_2CO_3	5.5 gr	27.5
K_2HPO_4	0.5 gr	2.5
NH_4Cl	2.5 gr	12.5

Table 2. Influent wastewater characteristics.

Substrate	Value
Temperature,°C	20-25
pH	6.5-7.5
Turbidity, NTU	78
TDS: Total dissolved solid, mg/L	125
TSS: Total suspended solid, mg/L	292
TOC: Total organic carbon, mg/L	56
DO: Dissolved oxygen, mg/L	2.2-3.6
COD: Chemical oxygen demand, mg/L	385
BOD_5: Biochemical oxygen demand, mg/L	170
LAS: Linear alkylbenzene sulfonate, mg/L	6.8

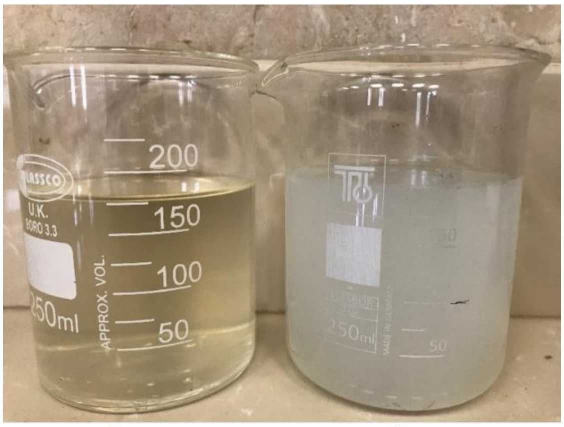

Fig. 3. Turbidity of a) treated wastewater and b) raw wastewater.

2.4. Reactor control and operating conditions

After the start-up of the system and sufficient growth of microorganisms, the utilization phase began with synthetic wastewater. Due to temperature control problems for application of this system at industrial scale and closer reactor conditions to actual conditions and optimal temperature (21 °C) (Fernandes 1994) the reactor was used at room temperature (20-25 °C). In order to keep the pH fixed in 7.0±0.5, commercial $NaHCO_3$ was used. During this period, the aeration continued at both stages of feeding and reaction until the amount of DO in the system was higher than 2 mg/L. SBR was operated in 6 cycles of 4 hours a day, including 2.5 h of aeration and mixing, 1 h of settling and 0.5 h of decanting (Fig. 2b, c and d). Because in SBRs timing of various stages of operation are essential, the setting of different stages from filling to discharge was done by automatic timers.

2.5. Analytical methods

Samples were collected at definite time intervals to estimate the wastewater compositions. Samples were filtered through 0.45 µm Whatman filter papers. Analytical procedures of DR5000 Spectrophotometer (Hach Company 2005) and standard methods for the examination of water and wastewater (APHA-AWWA-WEF 1992) were followed.The methods of 8006 (photometric, 5-57 mg/L), 10129 (direct, 15-15 mg/L), B2540 (total solids dried at 105-310 °C), E 2540 (Fixed solids and volatile solids at 550 °C) and C 2710 (SSV) were used to measure suspended solids (SS), TOC, MLSS, MLVSS and SVI, respectively. To measure DO, COD and BOD_5, DO meters (Micro logger O_2 ORBISPHERE), COD meters (Reactor COD BOX389, LOVELAND COLO.USA) and BOD meters (BOD_5 analis number FR21 HACH2173B Belgium) were used. In order to determine the amount of LAS, the method of C 5540 (anionic surfactants), Methylene Blue Active Substances (MBAS), was used.

3. Results and discussion

3.1. Experimental procedure

In general, a typical SBR includes five distinct phases namely fill, react, settle, draw and idle, while an advanced-SBR (ICEAS) consists of three phases namely react, settle and draw; which in all of these phases wastewater flows to the reactor and doesn't disrupt. Firstly, the wastewater enters into pre-react zone, with low MLSS concentration to create a high feed to microorganism (F/M) ratio that prevents filamentous growth causing sludge bulking. After a short retention time (15-20 min). The wastewater flows to main react zone through openings at the bottom of baffle wall. Distribution of wastewater is accomplished by "Distribution Tubes" that are installed at the bottom of the reactor. In react phase air diffusers act air supply and mixing of mixed liquor in the aeration basin. In settling phase, a thick sludge blanket is formed. This blanket is enough heavy to prevent disruption settled sludge. Organic constituent is used by microorganisms during passage of wastewater from this layer. In draw phase, clear supernatant in removed through a floating decanter. All of the decanted effluent is collected and analyzed. Experiment was done in three runs and by using the results, the effect of operating condition such as the time of various phases, especially aeration, on the removal efficiency of LAS, COD and BOD_5 was evaluated. The conditions for each of the three operating modes of the cycle are given in Table 3. Run 1: 6 cycle/d (t=4 h, Q=2.5 l/h), Run 2: 4 cycle/d (t=6 h, Q=2.0 l/h) and Run 3: 3 cycle/d (t=8 h, Q= 1.5 l/h).

Table 3. Operation cycle modes in ICEAS reactor.

Cyclic mode	Time, h			Flow, L/h
	React	Settle	Decant	
1	2.5	1.0	0.5	2.5
2	3.0	2.0	1.0	2.0
3	3.5	3.0	1.5	1.5

3.2. LAS removal

The LAS concentration variation with operation time under different operation cycle modes (first, second, third) in ICEAS. Influent LAS was about 6.8 mg/L. Effluent of LAS in cycle 1, 2 and 3 were 3.60 mg/L, 2.11 mg/L and 0.95 mg/L, respectively (Less than the limit LAS (1 mg/L) for irrigation purposes (WHO. 2006)). Fig. 4 is implied that longer time spent for each phase (aeration, settle and decant) higher LAS removal efficiency could be achieved and ensure the effluent quality improvement. LAS removal efficiencies for ICEAS operation cycle modes were as shown in Fig. 4 Therefore, maximum LAS removal efficiency of ICEAS was 86 % which occur at third cycle mode with 8 h duration time.

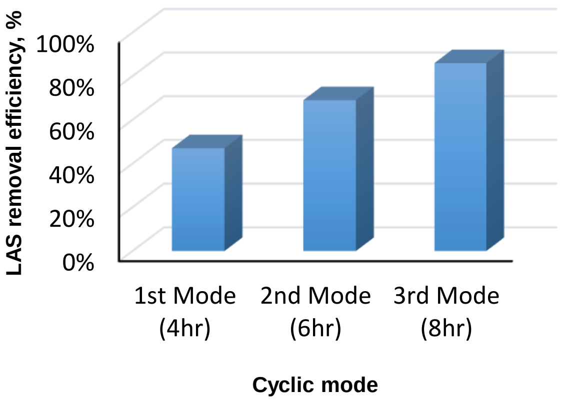

Fig. 4. LAS removal efficiency vs operation time.

3.3. COD reduction

COD in the feed and effluent were followed throughout the work. Soluble and total COD was measured. Influent total COD was about

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385 mg/L. Effluent of COD in cycle 1, 2 and 3 were 177.10 mg/L, 96.25 mg/L and 19.25 mg/L, respectively. Based on WHO (WHO.2006), effluents of 6hr and 8hr cycles are suitable for irrigation purposes as they have COD of less 100 mg/L. Fig. 5 shows system capability in COD reduction in different runs.

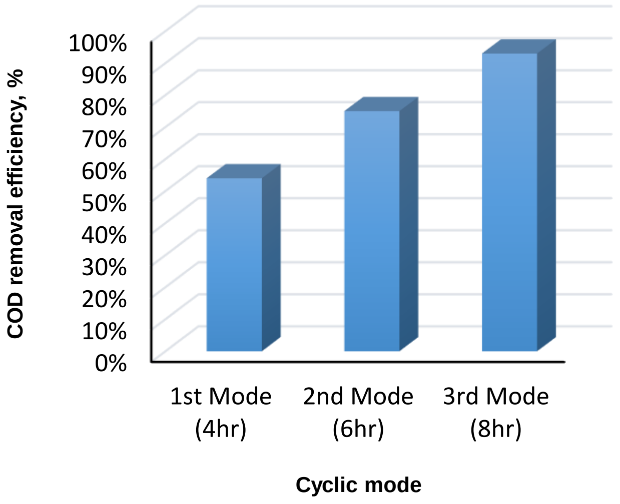

Fig. 5. COD reduction efficiency vs. operation time.

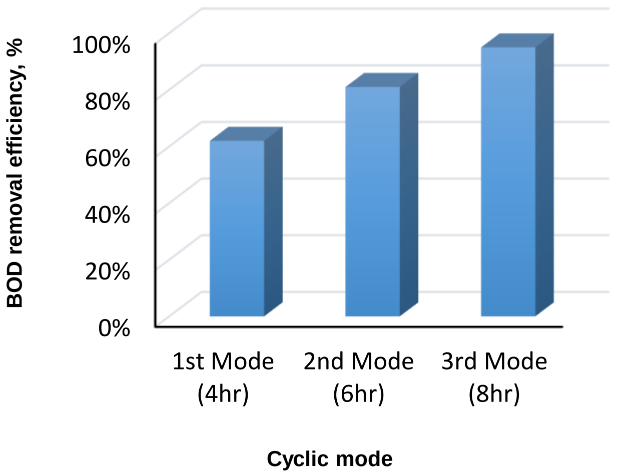

Fig. 6. BOD_5 reduction efficiency vs. operation time.

3.4. BOD_5 reduction

BOD_5 in the feed and effluent were followed throughout the work. Soluble and total BOD5 was measured. Influent total BOD_5 was about 170 mg/L. Effluent of BOD_5 in cycle 1, 2 and 3 were 64.6 mg/L, 32.3 mg/L and 8.5 mg/L, respectively. Based on WHO (WHO.2006), effluent of 8 h cycle is suitable for irrigation purposes as it has COD of less 20 mg/L. Fig. 6 shows system capability in BOD_5 reduction in different runs.

4. Conclusions

In this work, an advanced-SBR was used with 4, 6 and 8 hours cycles for bathroom greywater treatment. The amount of detergent in the effluent was lower than the standard discharge to surface water (1.5 mg/L) and to underground (0.5 mg/L). The results showed that the developed system has potential in the purification of graywater and the removal of pollutants such as detergent. The removal efficiency of 8hr cycle of LAS, COD and BOD_5 was 86%, 93% and 95%, respectively. Isolation and identification of indigenous bacteria (available in greywater) would help in reducing excess sludge production, this bacterium is more resistant to detergents, hence the time required for the adaptation of microorganisms to the treated contaminants will also decrease. We also suggest that our system's ability for wastewater treatment of petroleum companies, food industry and slaughterhouses is evaluated.

Nomenclature

ABS	Alkyl benzene sulfonates
ASS	Activated sludge system
BGW	Bathroom greywater
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
F/M	Food to microorganism
ICEAS	Intermittent cycle extended aeration system
LAS	Linear alkyl benzene sulfonates
MBAS	Methylene blue active substances
MLSS	Mixed liquor suspended solid
MLVSS	Mixed liquor volatile suspended solid
NTU	Nephelometric turbidity unit
SBR	Sequencing batch reactor
SSV	Settled sludge volume
SVI	Sludge volume index
TDS	Total dissolved solid
TOC	Total organic carbon
TSS	Total suspended solid
USEPA	United state environmental protection agency
WHO	World health organization

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