Treatment of Catering Wastewater Using a Combination of Up-Flow Anaerobic Sludge Blanket Followed by Down Flow Hanging Sponge Reactor

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Abstract: The viability of treating high-concentration of catering wastewater was studied by using a biological treatment system consists of combination of up-flow anaerobic sludge blanket reactor (UASB) as a pretreatment unit followed by down flow hanging sponge reactor (DHS)as a posttreatment unit. Raw wastewater has a high chemical oxygen demand, biological oxygen demand and total suspended solids with average concentration values of 3429 mgO_2/l, 1993 mgO_2/l and 1077 mg/l, respectively. The whole experimental period was divided into four distinct phases with different operating conditions. The theoretical overall organic loading rate (OLR) were 3.5 kg $COD/m^3.d$ and 0.6 kg $COD/m^3.d$ for UASB and DHS, respectively during the first phase; (5.7 and o.7 kg $COD/m^3.d$) during the second phase and (16.7 and 2.0 kg $COD/m^3.d$) at the third phase. During phase 4 the OLR was raised to 26.4 and 7.2 kg COD/m^3 .d. Organic pollutants were only partially removed in the UASB. The remaining organics as well as nitrogenous compounds were almost completely removed by the DHS unit. The proposed system achieves high removal efficiencies during the three phases. In the first phase, the percentage removal values were 87%, 92%, 93% and 92% for COD, BOD, TSS and Oil &Grease, respectively. Corresponding average values for second phase were 92%, 92%, 93% and 91%, respectively. For the third phase, removal efficiency was the same as the second phase. At the fourth organic load, the removal efficiency decreased by 9±5**%.** Based on the results obtained, the proposed system showed high performance for the treatment of wastewater, and also exhibited high stability against organic shock load. So, the aim of this work was to investigate a simple, low cost integrated system for treatment of high strength wastewater to produce treated effluent complies with the national regulatory standards for discharging into the sewerage system.

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Introduction

Food industries in general produce large quantities of wastewater, and the catering process is one of these industries. The catering establishments typically generate large volumes of wastewater. It is reckoned that approximately 10 liters of wastewater is produced in a canteen for every meal. The wastewater composition vary from time–to-time, thus it is very difficult to obtain a meaningful characterization, Xueming Chen *et al*, (2000). The wastewater is heavily polluted, which contains significant concentration of biodegradable organic materials and suspended solids. It is rich in sugar, carbohydrate, protein, fat, oil & grease collectively termed (FOG); and other nutrients which mainly come from grain, meat, bones, eggs and other animal tissues (Lin *et al*.,2013, Mena, *et al*, 2011 and Ying An *et al.* 2014). Williams J.B *et al*, (2012) and FAO (2010) stated that in developing countries the capita FOG consumption is about 20 kg/a. FOG deposits reduce sewer diameters and completely block pipes (Ashley *et al.* 2000) causing the flooding of sewers. Moreover, the high amount of wastewater flow, load and daily fluctuations exertes negative impact on sewerage system and the municipal treatment plant performance (El-Kamah *et al*, 2010). Thus this wastewater must be properly treated to the degree necessary to comply with the regulatory standards for discharge established by environmental agencies (Chan *et al*, 2010). Many researchers reported the extensive utilization of the sequential anaerobic /aerobic processes to treat the wastewater generating from food industry (Malaspine F. *et al*, 1995, Hala *et al* 2011). The anaerobic treatment systems, especially the Up-flow Anaerobic Sludge Blanket (UASB), represent low cost and sustainable technology for the treatment of high strength organic matter wastewater including food industry, because of its low construction, operation and maintenance costs; small land requirement; low excess sludge production and biogas production (Lettinga *et al* 1993, Rajeshwari, K.V. *et al*., 2000, Van Lier J.B. *et al.* 2001). Unfortunately, UASB is considered as a pretreatment unit, the effluent of which still contains residual organic matters and nutrients (Draaijer *et al*.1992; Shellinkhout *et al*.1993; Tandukar M. *et al*. 2006).

These facts clearly suggest that the use of UASB only cannot reliably meet the effluent standards established by environmental agencies. Therefore, the effluents from anaerobic treatment usually require a post treatment step for further treatment to meet the requirements of the environmental legislation. The main role of the post treatment is to complete the removal of organic matter, nutrients (N and P) and Pathogenic organisms (Chernicharo 2006). Various aerobic systems have been applied as post treatment, such as submerged aerated biofilter (Collivignarelli *et al.*, 1990), aerobic fluidized bed, rotating biological contactor (Castillo *et al*., 1997), activated sludge (Sperling *et al*., 2001) and down flow hanging sponge (Machdar *et al*., 1997). Recently the Down flow hanging sponge (DHS) reactor has been proposed as an appropriate and effective solution for post treatment (Agrawal *et al.,* 1997; Machdar *et al*., 2000; Uemura *et al* 2002, El-Kamah *et al*., 2011). The DHS reactor is a novel bio tower –TF system with polyurethane packing which offer several advantages such as higher biomass concentration, higher sludge residence time, lower hydraulic retention time, excellent degradation efficiency, high effluent quality, low cost and small foot print compared to conventional aerobic bioreactors (Tandukar *et al*., 2007; Mahmoud *et al*.,2011; Tawfik,2011). One of the major advantages of the DHS system is there is no external aeration is required because as the sponge in DHS is not submerged and freely hung in the air oxygen dissolved into the wastewater as it flows down. This mechanism maintains the dissolved oxygen (DO) concentration at a level which exceeds the need of aerobes residing in DHS sponge (Tandukar *et al*.,2006). The Sponge used in the DHS has been considered as an ideal attached growth medium because it can act as a mobile carrier for active biomass, reduce the cake layers formed on the surface of membrane and retain micro-organisms by incorporating a hybrid growth system (both their attached and suspended growths) (Ngo H.H. *et al.,* 2006, Wenshan Guo *et al*., 2009).

In the present study, the viability of treating high-concentration of catering wastewater was investigated by using integrated system consists of a combination of (UASB) followed by (DHS). The investigated research was carried out using four different organic and hydraulic loading rates.

2. Materials and Methods

2.1. Wastewater

The wastewater used in this study was derived from catering facility in industrial city outside Cairo. A continuous monitoring programme under normal operating conditions for end off pipe was employed to characterize wastewater quality.

2.2. Laboratory scale of biological treatment system

The integrated system (UASB+DHS) was installed and operated at the experimental site in the National Research Centre, Cairo, Egypt.

2.2.1 The UASB reactor was manufactured from poly-vinyl chloride (PVC) with an effective volume of 5 L. It consisted of a cylindrical column with a conical shaped bottom and equipped in the upper part with gas-solid separator (GSS) for separating solids and collecting the produced gas Figure (1). It was seeded with digested sewage sludge obtained from pilot plant anaerobic hybrid reactor treating municipal wastewater. The sludge had a concentration of 12gVSS/l. The total suspended solids (TSS) content of the sludge was 4% and the volatile suspended solids (VSS) was 2.5%. The specific methanogenic activity of the sludge was 0.02 gCH_4-COD/gVSS/day. The system was operated by feeding raw wastewater from an equalizing tank installed provided a storage facility enabling the experiment to be carried over a full 24 hrs.

2.2.2. DHS reactor was 4.1 L, based on the sponge volume. Polyurethane sponge with pore size of 0.63 mm was used for the construction of DHS. Void ratio of sponge was more than 90%. The dimensions of the used polyurethane sponge PF (cylindrical shape) were 35 mm height ×22 mm diameter. A rotary type wastewater distributor was set up at the top of DHS reactor. A small clarifier was also set at the bottom of the DHS to trap excess sludge from it, if any. The oxygen is naturally diffused through tow windows located along the height of DHS reactor for sampling. Treated effluent from UASB reactor was then directly fed to DHS reactor, which flowed down under the effect of gravity. The system was continuously operated at ambient temperature of 25 ± 5^0C.

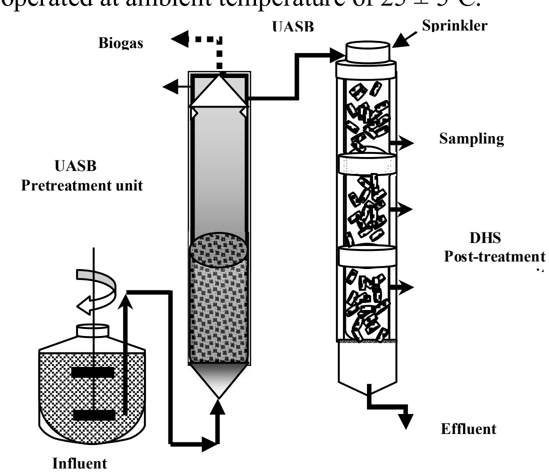


Figure (1) Schematic Diagram for the Combined System (UASB+DHS)

2.3 Startup and operation of the integrated system

The integrated system was initially started to operate after 1 month of adaptation period with raw wastewater. During the start-up period, the applied organic load was increased gradually. The UASB reactor was operated for 18–30 days before starting to operate in every phase in order to reach steady-state conditions. Steady state was defined by the constant effluent COD concentration within 5% variation for three consecutive measurements. After the reactor had achieved stable operating conditions, the HRT was decreased. After reaching the steady state; the system was continuously operated for 170 days which was divided into four phases. Table (1) summarizes the operational parameters of the combined system.

Table (1) The operation conditions of the combined system

Parameter	Phase 1		Phase 2		Phase 3		Phase 4	
	UASB	DHS	UASB	DHS	UASB	DHS	UASB	DHS
HRT (h)	24	19.7	12	8.16	6	9.1	3	2
Organic loading Rate (OLR) kg COD/m^3.d	3.5	0.62	5.7	0.7	16.7	2.02	26.4	7.2

2.4 Analytical methods

The performance of the combined treatment system was monitored by analyzing raw wastewater, the effluents from UASB and DHS reactors. Dissolved oxygen, pH and temperature were measured regularly in situ. The physico-chemical analysis covered: Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), oil and grease. The analyses were carried out according to APHA (2012).

2.5 Batch bioassay

The bioassay test was carried out to determine the aerobic and anaerobic biodegradability of the catering wastewater.

2.5.1 Aerobic biodegradability: A mixture of raw wastewater, mineral nutrients and 3-5g/l total solids of activated sludge was agitated at room temperature for about 35 days in 2 liter container. Blank controls, containing the same volume of activated sludge and mineral nutrients but no wastewater added were run in parallel. The biodegradation process was monitored by BOD in filtered sample and DO taken daily. The ratio of BOD elimination, corrected for the blank, to the initial BOD value is expressed as the percentage biodegradation.

2.5.2 Anaerobic biodegradability: The test was performed in a recirculated digester, 2 liters volume with effective volume 1.8 liters. It was carried out for a period of 40 days and were placed in room temperature 25±5. Essential inorganic macro and micro nutrients were added to bioassay test, (Zehender, 1976 and Sierra-Alvarez and Lettinga, 1990). The degree of Hydrolysis (H), Acidification (A), Methanogensis (M) and Biodegrdability (BD) were monitored.

3.Results and Discussion

3.1 Characterization of wastewater:

The wastewater from catering facility was analyzed; averages results and standard deviation of 40 samples are given in Table (2) and illustrated in Figures (2 &3).The results showed that wastewater characteristics are higher in strength than residential wastewater. The composition of the wastewater depends on the production process. The high levels of oil & grease, due to the fried foods in the collected feedstock, cause higher biochemical and chemical oxygen demand (BOD & COD). Oil and grease frequently cause problems for both onsite sewage disposal systems and public sewer systems.

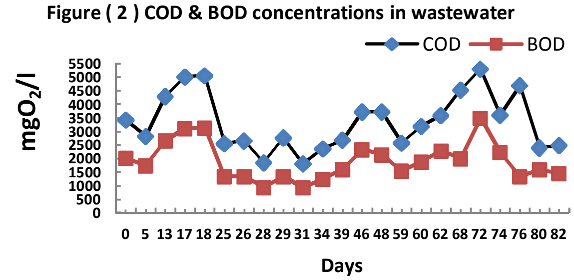
Table (2) Average characteristics of food catering wastewater

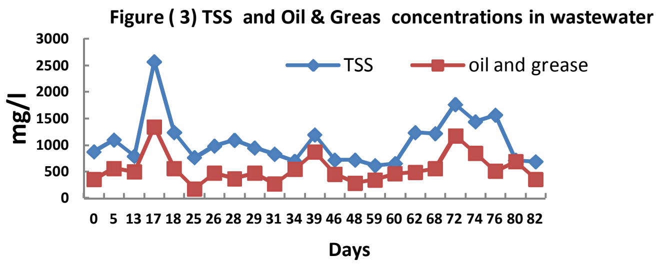
Parameters	Average	S.D.*
pH	7.8	±0.2
COD	3307.3	±1043
BOD	1666	±697
TSS	1103.5	±525
TKN	65	±17
NH_3	35	±9.3
Tot.P	4.6	±3
Oil & Grease	311	±241
*Average of 40 samples		

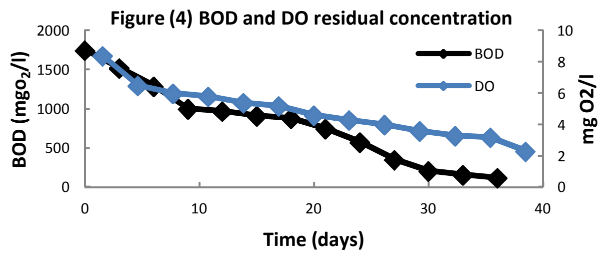
3.2 Biodegradability: The biodegradation of the catering wastewater have been estimated under both aerobic and anaerobic conditions.

(a) The aerobic biodegradability: According to the results obtained it was found that the BOD decreased by 50% after the first week. Average percentage biodegradability reached 77% after 14 days and it gradually decreased to 50% during the following 12 days Figure (4). DO levels were 8.4 mgO_2/l at the beginning of the test and then it dropped to 5.4 mgO_2/l after 10 days. During the following 36 days the DO dropped gradually till it reached 2 mgO_2/l; at the end of the test.

Figure (2) COD & BOD concentrations in wastewater



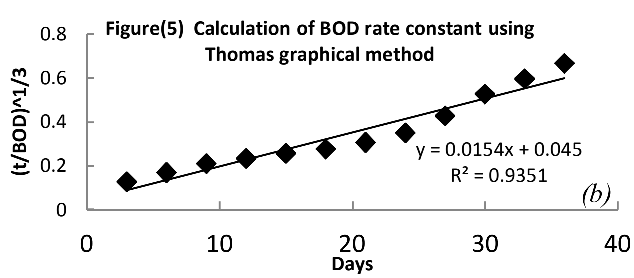




Thomas graphical method was applied to determine BOD rate constant (*K*) and ultimate BOD (L_o) (Davis M.L. & Cornwell D.F, 1998; and Najafpour G.D *et al*., 2006). Thomas relationship is given by the following equation:

$$\left(\frac{t}{BODt}\right)^{1/3} = \frac{1}{(kLo)^{1/3}} + \frac{(k)^{2/3}}{6(Lo)^{1/3}} * t$$

The linear graph based on Thomas graphical method is shown in Figure (5). The value of BOD rate constant (*k*) and ultimate BOD (L_o) were 0.5/day and 1723 mg/l, respectively.



Anaerobic batch bioassay: The results obtained showed that COD soluble (COD_{sol}) and COD total (COD_{tot}) were measured for 42 days as well as the gas production. The results obtained illustrated and recorded in (Figure 6).

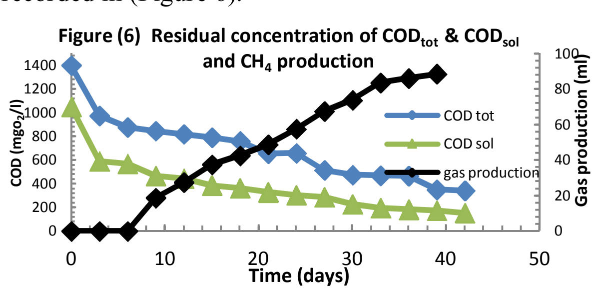


Table (3) summarizes the calculated percentages of hydrolysis, acidification and methanogenesis for the wastewater sample after 42 days of digestion. Tarek A. Elmitwalli *et al.,* (2001), stated that the results were calculated according to equations (1), (2) and (3), respectively:

$$H(\%) = 100 \times \frac{CH_4\ as\ COD + effluent\ COD_{sol} - influent\ COD_{sol}}{influent\ COD_t} \quad .(1)$$

$$A(\%) = 100 \times \frac{CH_4\ as\ COD + effluent\ VFA - influent\ VFA}{influent\ COD_t} \quad ....(2)$$

$$M(\%) = 100 \times \frac{CH_4\ as\ COD}{influent\ COD_t} .... (3)$$

The results of total CH_4 production in the batch biodegradability test showed that the maximum conversion of the wastewater was obtained after 36 days. It is obvious that the methanogensis percentage was decreased to 45%; this may be due to the entrapment of the coarse and finely suspended solids from the wastewater in the sludge. This may lead to the entrapment of the sludge bacterial matter which may ultimately result in a sever decrease in the methanogenic bacterial concentration, it will also hamper the supply of the substrate to the bacteria present in the sludge aggregate (Lettinga *et al*.,1983 and Grin *et al*.,1985).The biodegradability percentage of the wastewater equal 46%, of the total COD and 32% for the soluble COD.

Table (3) Percentage of Hydrolysis (H), Acidification (A) and Methanogensis (M) for wastewater after 42 days of digestion.

Parameters	H (%)	A (%)	M (%)
	20%	48%	45%

3.3 Performance of the integrated system (UASB and DHS)

The combined system was operated successfully during the whole experimental duration time: 24 weeks and four different organic loads without any system failure. The UASB was fed with catering wastewater without any treatment. The performance of the combined system during the four applied organic loads was summarized in Tables (4& 5) and illustrated in Figures (7a,b,c & d and 8a,b,c&d).

Table (4) Summarized overview of process performance of the combined system during the four phases

Parameters	Raw wastewater	Phase1		Phase 2		Phase 3		Phase 4	
		UASB	DHS	UASB	DHS	UASB	DHS	UASB	DHS
pH	7.5 ± 1	7.8±0.1	8.3±0.2	7.9±0.3	8.5±0.2	8±0.2	8±0.2	8±0.1	8.4±0.1
COD	3244 ± 979	1085±311	405±169	949±358	204±45	1320±428	198±63	1207±284	479±231
BOD	1741±596	549±221	148±56	534±210	112±65	776±325	91±16	793±115	354±84
TSS	1023±388	189±64	67±25	200±41	61±25	266±250	68±35	244±70	95±35
TKN	70±17	41±12	22±16	54±22	34±15	50±11	21±3	39±6	18±5
Oil & Grease	507±261	169±85	42±22	86±35	33±14	156±113	38±14	91±35	50±23

Phase 1: The organic loading rate of the UASB and DHS were 3.5 and 0.62 kg COD/m^3/day, respectively. UASB removal efficiency for COD and BOD was 67% and 72%, with residual concentration values of 1085 and 549 mgO_2/l, respectively; this does not meet the national standard for discharging wastewater into the sewerage system. But after post treatment using the DHS, removal efficiency of COD and BOD was 62% &73% with residual concentration values of 405 and 148 mgO_2/l, respectively. It was found that 82% of TSS was entrapped within the sludge of the UASB and only 61% in the DHS. Moreover, 87% of oil& grease was removed by UASB and 75% by DHS, discharging only 42 mg/l in the final effluent.

The overall efficiency of the integrated system in phase 1: It was found that COD & BOD removal values were 87% and 92%, respectively. Total removal of TSS was 93%; with average residual concentration of 67 mg/l. The system proved to be excellent in the removal of organic matter which attributed to a large amount of active biomass retained in the sponge material which amounted to 10gVSS/l of sponge volume. The value is about 5 times higher than that of the activated sludge system (Metcalf & Eddy 2003). Tandukar M. *et al*., (2006) stated that the high concentration of retained biomass in the DHS is capable of removing large amounts of organic material in a short period of time.

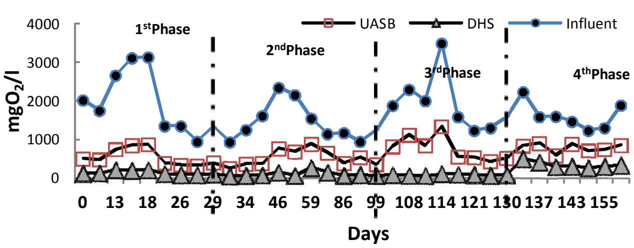


Figure (7,a) Effect of combined system on the BOD concentration

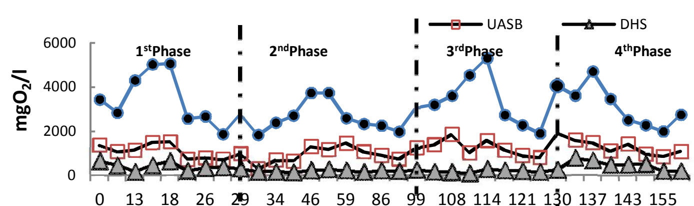


Figure (7,b)Effect of combined system on the COD concentration

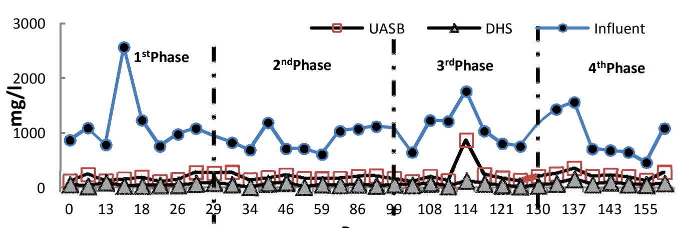


Figure (7,c)Effect of combined system on the TSS concentration

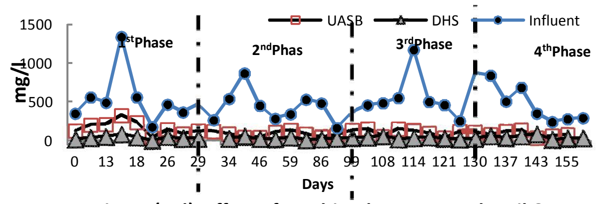


Figure (7,d) Effect of combined system on the oil & grease concentration

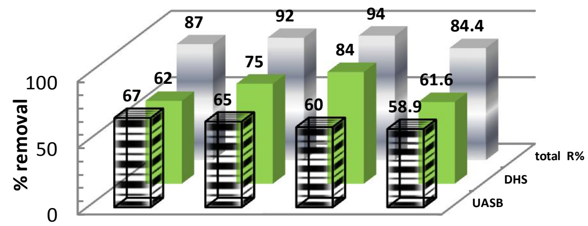


Figure (8,a) the % COD removal and the total performane

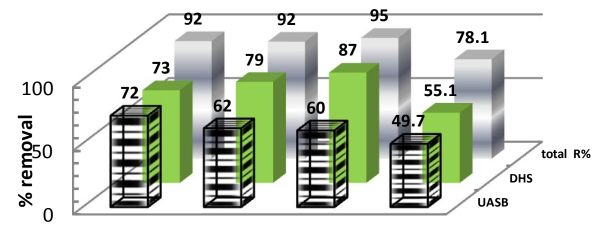


Figure (8,b) % BOD removal and the total performance

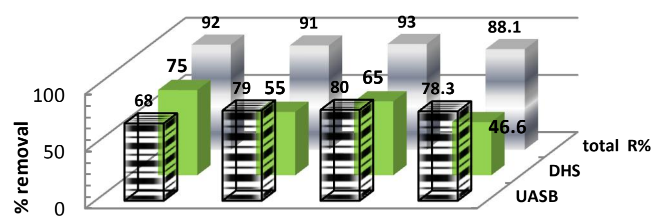


Figure (8,c) % Oil & Grease removal and the total performance

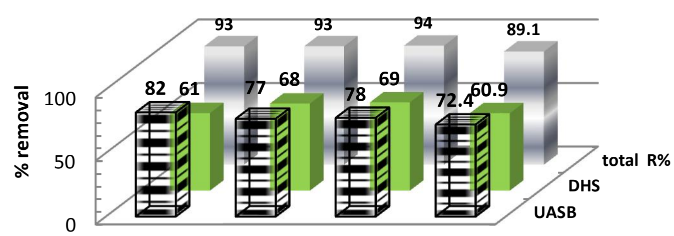


Figure (8,d) % TSS removal and the total performance

Table (5) Overall Removal Percentage of the integrated combined system

parameters	Phase 1	Phase 2	Phase 3	Phase 4
COD % Removal	87	92	94	84
BOD% Removal	92	92	95	78
TSS% Removal	93	93	94	89
Oil & Grease% Removal	92	91	93	88

Phase 2: During the second phase, organic loading rate increased to 5.7 and 0.7 kg COD/m^3.d for UASB & DHS, respectively. Removal efficiency of COD and BOD were 65% and 62% for UASB reactor and increased to 75% and 79% for DHS reactor. The removal percentage of oil & grease was 79% and 55% for UASB and DHS, respectively. Performance of the DHS system improved more than the previous phases. A possible explanation is that the increase in down-flow velocity enhanced the dissolution of air into the wastewater, providing more oxygen to the aerobic microorganism inside the sponge. DO is absent in UASB effluent, as the wastewater flows in the DHS, the oxygen concentration increases to the value of 3-5 mg/l in the effluent. Also, the higher flow rate increased the penetration of wastewater deep into the sponge material facilitating better substrate distribution (Tandukar M. *et al*., 2006).

The performance of the combined system (UASB + DHS) fluctuated with the change in the wastewater quality. Total removal efficiency of the COD, BOD, and TSS was 92 %, 92% and 93%, respectively. Moreover, the total removal efficiency of oil and grease was 91%, discharging only 33 mg/l in the final effluent.

Phase 3: The organic loading rate increased to 16.7 and 2 kg COD/m^3.d for UASB & DHS, respectively. COD removal percentage by UASB slightly decreased than the previous phase by only 5% to be 60% but by DHS, it increased by 10 % to be 84%. Available data indicated that increasing the applied organic load did not exert significant negative impact on the reactor performance. The overall removal percentage of the combined system (UASB + DHS) of COD was 94%, with a residual concentration value of 198 mgO_2/l. Total removal percentage of TSS was 94% with a residual concentration value of 68 mg/l. . Whereas, the Oil and grease total removal percentage reached 93%, with an average residual value of 38 mg/l only.

Phase 4: The organic loading rate rose to 26 and 7 kg COD/m^3.d for UASB and DHS, respectively. The total organic removal values were decreased. COD removal efficiency reached 59% for UASB and 61% for DHS reactor. The BOD removal percentage reached 49 and 55% for UASB and DHS, respectively (Figure 8).

The overall removal percentage of the combined system for (COD & BOD) was 84% and 78% discharging effluent concentration values of 479 mgO_2/l for COD and 354 mgO_2/l for BOD. The overall removal percentage of the TSS decreased to 89% while the TSS concentration value increased to 95 mg/l, in the final effluent. This was explained by Tandukar M. et al., (2006), who stated that increasing the hydraulic load may lead to disruption of the retained sludge inside the sponge of the DHS which leads to an increase in the suspended solids in the final effluent. Moreover, Oil & grease removal efficiency was 78% by the UASB and 47% by the DHS, discharging 50mg/l in the final effluent.

Conclusion: A biological treatment system consisting of the UASB followed by the DHS reactor was applied for treating catering wastewater at 25ºC. The system can produce high quality effluent which complies with the legislation standard for discharging in the sewerage system. It was found that the rising of the organic loading rate did not have a negative impact on the system's performance. The results showed that the integrated system (UASB+DHS) reduced the organic pollutants by 92% and 95% for COD and BOD, with residual concentration values of 198 and 91 mgO_2/l, respectively. The proposed system has many advantages as good performance, simple operation, low cost and energy conservative, thus it can be a good alternative for the conventional treatment system. Therefore, the combined system can be recommended for the treatment of high strength wastewater as catering industry.

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