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Anaerobic up flow fluidized bed reactor performance as a primary treatment unit in domestic wastewater treatment



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KEYWORDS

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Abstract The fluidized bed UASB performance was studied in this experiment as a primary unit the anaerobic unit the advantage of better generated sludge characteristics and smaller tank volume.

The reactor performance was investigated for the treatment of domestic wastewater with unexpected industrial water flows at different operational temperatures (14–25 °C) and loading rates. For each temperature range the reactor performance was studied under different hydraulic loadings HRT (6, 4, 2.5 h).

The best methane yield rate and COD total removal rate are 0.285 l/g COD total and 70.82% respectively at warm working temperature 19 °C with OLR 7.76 kg COD/m³/day and HRT 6 h.

On the low temperature operation, the average COD removal of the reactor was 55.28% and 50.33% for HRT of 4 h and 2.5 h respectively. The methane production dropped to 0.1623 & 0.0988 L CH₄/g COD with average organic loading rate of 5.34 & 10 kg COD/m³/day for HRT of 4 h and 2.5 h respectively.

The efficiencies of Total nitrogen removal ranged between 2.23 and 10.83% with an apparent decrease during the low temperature high rate stages. Nitrite removal was in the range of (23.08–77)% with up to the 2 mg/L in the effluent water when obtaining high organic loading and warm temperature. These results demonstrated that the domestic wastewater could be anaerobically treated in a fluidized bed UASB reactor with very low HRT reaching 2.5 h.

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Abbreviations: UASB, up flow anaerobic sludge blanket; GSS, gas-solid separator; HRT, hydraulic retention time; SRT, sludge retention time; WWTP, wastewater treatment plant; OLR, organic loading rate

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Introduction

The conventional aerobic processes that are widely used for the treatment of domestic wastewater have at least three distinct disadvantages: their relatively high electrical requirement, the high operation cost and the high excess sludge production which requires treatment and disposal that further increases the operational cost.



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On the other hand anaerobic processes produce methane gas that can be collected and used as an energy source in addition to the low energy consumption. The sludge production is also minimal, and additional important benefit is that the anaerobic sludge can be preserved while not being fed for long periods of time at temperature below 15 °C [1].

The feasibility of the up flow anaerobic sludge blanket reactors UASB for adequate sewage treatment has been investigated since 1980 at both pilot and full scale installations [2], but at the moment, it is largely restricted to countries with a relatively cold climate [3].

The anaerobic fluidized bed and the expanded granular sludge bed reactors, with HRTs of about 2–4 h [4] and the UASB reactor, with an HRT of 4–8 h [5] offer good results, while the attached growth process named anaerobic filter needs a longer HRT on assuming constant organic loading rates for all systems.

As domestic wastewater flows are relatively huge in large cities and should be treated at short HRTs to be more feasible and often are at ambient or low temperatures, complex substrates could leave the reactor before being biodegraded. In UASB systems, with relatively adequate HRT, the sludge bed acts as a filter to the SS, thereby increasing their specific residence time. In this way, the UASB reactor may achieve high COD and SS removals at a relatively short HRT if compared to the conventional primary sedimentation tanks. Consequently one of the aims of the study was to study the influence of the low HRT on the reactor performance.

Material and methods

The Experimental work was carried out at El Berka wastewater treatment plant. Using domestic wastewater from the primary sedimentation channel the experimenting set up was started by the UASB reactor.

The reactor consists of a column portion (130 cm) of about 23 L and a gas–solid separator (GSS) portion (20 cm) of about 6.28 L. The reactor total volume is about 25.60 L this volume was used to calculate the organic loading and the hydraulic retention time. The UASB was operated over 100 day under different temperature ranges (15–25) °C.

The up flow velocity was varied according to the hydraulic retention time HRT variation, no recirculation was applied. Effluent recycle was not necessary to fluidize the sludge bed as sufficient contact between the wastewater and sludge is guaranteed even at low organic loading rate in UASB reactor [6]. Fig. 1 shows the reactor setup and the influent water characteristics are shown in Table 1.

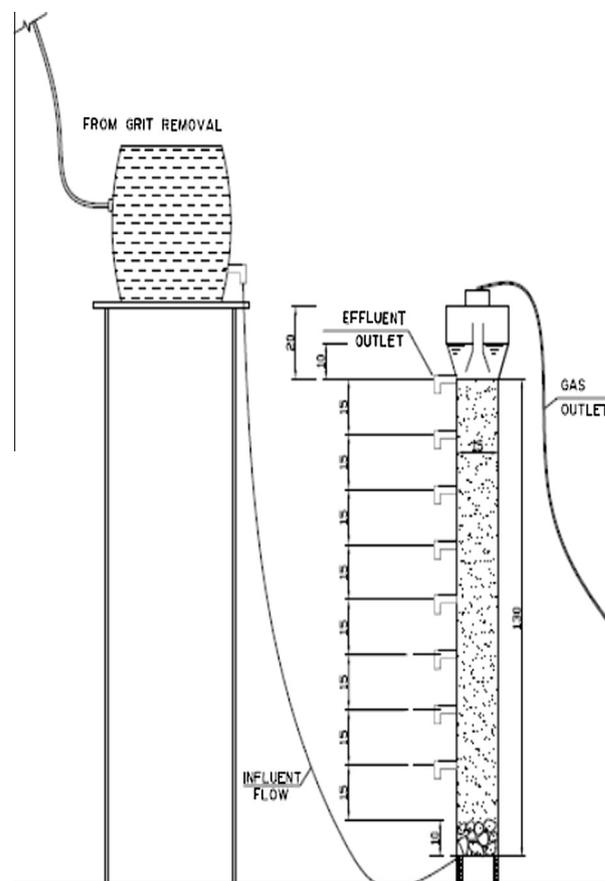


Fig. 1 Reactor set up.

Experimental methodology

The reactor was operated at ambient temperature, no heat exchange was introduced. The reactor was operated in the autumn/winter time where the temperature falls down in winter reaching about 15 °C. The average influent wastewater temperature during the experiment is shown in Table 2.

The experiment routine water analysis was done according to the standard method for water and wastewater analysis [4], the physical and chemical analysis included the measure of chemical oxygen demand (COD) and the sulfate concentration of influent and effluent was analyzed by DR-2800 spectrophotometer (HACH company, USA) in accordance with manufacturer's manual. Raw samples were used for total COD and 0.45 µm-filtered samples for dissolved COD. After sampling,

Table 1 Influent water characteristics.

Parameters	Unit	Min.	Average	Max.
pH-value	–	6.71	7.44	7.93
Chemical oxygen demand(COD)	(mg/L)	400	1105	2240
Biological oxygen demand(BOD)	(mg/L)	178	695	1913
Total suspended solids (TSS)	(mg/L)	172	788.60	2080
Total volatile solids (VSS)	(mg/L)	120	532	1410
Total nitrogen (TN)	(mg/L)	47.20	52.75	58.30
Ammonia (NH ₄ -N)	(mg/L)	15	28.10	41.60
Nitrate (NO ₃ -N)	(mg/L)	2.5	7	11.50
Nitrite (NO ₂ -N)	(mg/L)	9	11.50	14

Table 2 Experiment operational parameters.

HRT (h)	V_{up} (m/h)	COD _{influent} (mg/L)	OLR (kg COD/m ³ day)	Temperature (Degree centigrade)
Stage (1): reactor start up (6–8)	(0.18–0.24)	(640–1643)	(1.87–4.81)	(21–25)
Stage (2): HRT = 6 h	0.24	(640–1998)	(2.5–7.76)	(21–25)
Stage (3): HRT = 4 h	0.35	400–1600	(2.44–9.37)	(21–25)
Stage (4): HRT = 2.5 h	0.56	(1065–2240)	(10.38–21.85)	(21–25)
Stage (5): HRT = 4 h low Temperature	0.35	(736–1072)	(4.31–6.28)	(14–16)
Stage (6): HRT = 2.5 h low Temperature	0.56	(464–1728)	(4.53–16.86)	(14–16)

effluent was homogenized for suspended solids (SS) and total COD measurement. The COD removal efficiency was calculated by the different between influent total COD and effluent total COD, though many UASB researches calculate the difference between the total influent COD and soluble effluent COD [7]. The Biological oxygen demand (BOD), total suspended solids (TSS), total volatile solids (VSS), pH, and alkalinity were also measured. Gas production rate was measured by water displacement. It should be mentioned that the CH₄ in the liquid phase as well as the effluent water escaped gas is not measured.

The volatile Fatty acid (VFA) was measured for each Stage to monitor any accumulation of volatile acids (acetate, butyric, propionic, etc.) which inhibits the methanogenic bacterial degradation action. Fig. 4-1 shows the reactor setup. The experiment operational parameters are shown in Table 4-3.

The reactor was fed with anaerobic flocculent sludge collected from a pilot study digester for the domestic wastewater sludge in El Berka WWTP. The inoculum sludge characteristic is shown in Table 3.

Results and discussion

The startup period began on the 19th of October, 2013 where the water temperature in El Berka WWTP water (23–25) °C. A range of (25–30) °C is generally preferred to support more optimum biological reaction rates and to provide more stable treatment [9]. Then the experiment continued in the winter temperature where the temperature ranged between 14 and 16 °C.

Experts suggest that the hydraulic retention times (HRTs) should not be allowed to less than 6 h and it should be less than 18 h during start-up period to treat any type of wastewater. At lower HRT, the possibility of washout is more prominent. This makes it difficult to maintain the effective number of useful microorganisms in the system [10].

Table 3 Characteristics of the inoculated sludge.

Parameter	Value	Units
TSS	4460	mg/L
VSS	3340	mg/L

During the startup period the wastewater load on El Berka WWTP was high and the COD loading reached about 2000 mg/L, and was reflected on the organic loading fed to the UASB reactor. Then afterward the COD organic loading was in the average range of the treatment plant which ranges between 400 and 600 mg/L. Fig. 3 shows the average influent and effluent COD as well as the COD removal efficiency during the startup period.

The Total alkalinity as calcium carbonate equivalent was also monitored, the alkalinity monitoring importance prevails the assessment of pH, and since the pH values imply the consumption of high amount of alkalinity, reducing the buffering capacity of the medium.

In an anaerobic digester, a bicarbonate alkalinity (as CaCO₃) of about 1000–3000 mg/L was required for stable operation [11]. Disparity to this, an average alkalinity with a range of 220–390 mg/L was successful for the operation of a UASB reactor over 200 days [2]. On this basis, sufficient alkalinity was available in the reactor that causes no drop in the pH during the experiment period; Fig. 2 shows the reactor alkalinity during the experiment.

The VFA value of the treated effluent was monitored during the startup stage. Methanogenesis, in particular is known to become unstable when the VFA/alkalinity ratio value is above 0.3 [12,13]. Throughout the experiment the effluent VFA values were in range of (78–139) mg/L. and the VFA/Alkalinity ration ranged between 0.1 and 0.124.

During start-up period COD:N:P ratio reached 293:4:1. COD, N and P Supplementation were not done as it was very near to the range stated in the literatures 300:5:1 for efficient rapid start-up [14,15].

Biogas production

The biogas during the experiment was measured by water displacement method. Table 4 shows the measured biogas production rate and the calculated methane converted to methane gas over the entire experimental period for the warm and cold temperatures. The volumetric methane production rate and the organic loading rate are illustrated in Fig. 4.

The methane gas production along with the experiment ranged between 71 and 285 mL/g COD removed. The rate of gas production was lower than the theoretical value of 350 mL/g COD removed reported by Metcalf and Eddy [9]. It may be due to the effects of ammonia nitrogen present in

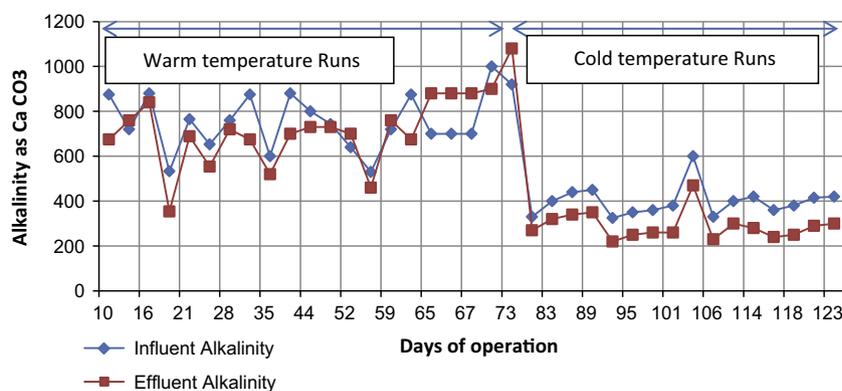


Fig. 2 Influent and effluent alkalinity during the experiment.

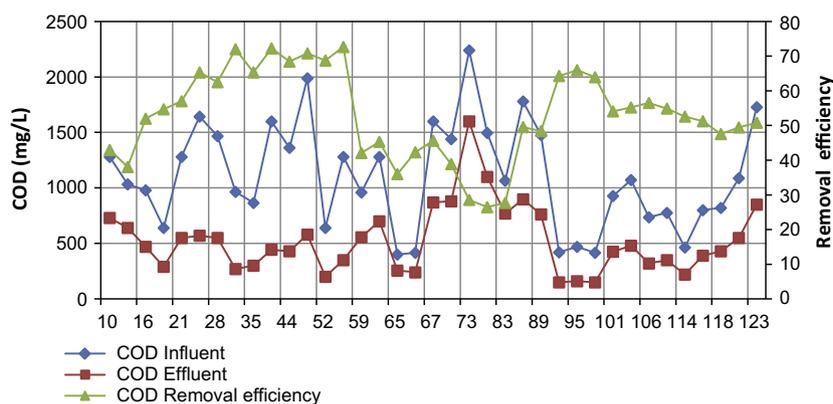


Fig. 3 COD influent, UASB effluent and COD removal efficiency.

Table 4 Biogas production.

Phase	Organic loading rate (kg COD/m ³ /day)	HRT (h)	Conversion factor (Liters CH ₄ /g COD)	Biogas production (Liters/g COD removed/day)
Stage (1)	(1.87–4.81)	(6–8)	0.220	11.57
Stage (2)	(2.5–7.76)	6	0.256	20.15
Stage (3)	(2.44–9.37)	4	0.198	8.36
Stage (4)	(2.44–9.37)	2.5	0.143	7.57
Stage (5)	(4.31–6.28)	4	0.162	7.15
Stage (6)	(4.53–16.86)	2.5	0.098	3.43

concentrations higher than the beneficiary levels in the influent.

At HRT below 4 h the measured methane Gas production was decreased to its minimum range (71 mL/g COD removed). This can be attributed to the low temperature range and higher organic loading rate. Low temperature, high loading rate with high per stage of SS all result the shorter SRT and lower down the biogas production and COD removal efficiency [16,17].

It should be noticed that in this experiment the measured methane was only the free methane gas while at low HRT the ration between soluble methane and methane gas production increases [7]. Consequently the calculated conversion rate may be no accurate.

Influent and effluent water TSS and VSS

During the startup period the reactor TSS removal was quite sufficient as the up flow velocity was low (0.4 m/h), the gas production rate was low ranging between 4.89 and 12.05 (l/g COD removed/day) and the washout was avoided. When the HRT was decreased the up flow velocity was increased to decrease the TSS and VSS removal efficiency.

During the cold temperature Runs the anaerobic microorganisms and in specific the methanogenic bacteria growth was declined leading to lower reactor performance and the accumulation of the suspended solids in the reactor that leads

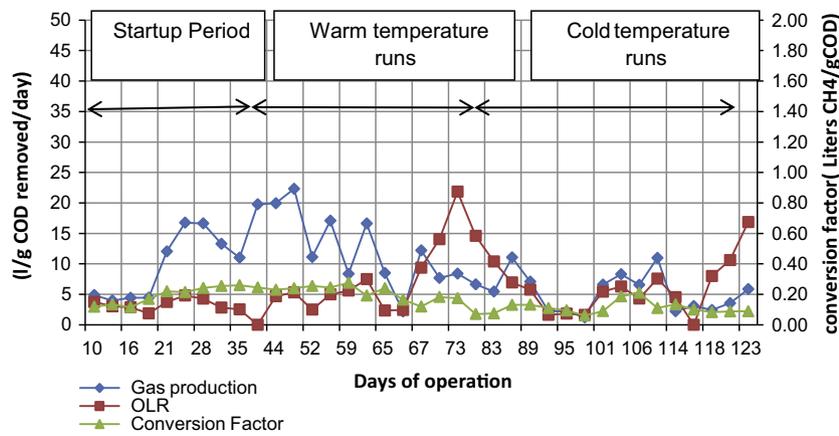


Fig. 4 Biogas Production.

Table 5 Average TSS & VSS of influent and effluent waters during the experiment.

Phase	TSS			VSS		
	Influent	Effluent	Removal%	Influent	Effluent	Removal%
Stage (1)	220–543	70–165	68.18–72.97	140–230	42–60	69.44–73.91
Stage (2)	172–2080	67–541	58.47–73.99	120–1410	45–365	62.5–74.11
Stage (3)	218–1230	120–789	33.33–58	148–830	78–530	33.78–50.32
Stage (4)	530–1254	388–824	26.79–34.29	360–730	221–543	24.49–38.61
Stage (5)	236–2000	130–845	44.92–57.75	160–1360	88–754	38–45
Stage (6)	450–1500	283–687	33.33–55.71	305–1130	200–626	34.43–46.02

to the rising of the sludge blanket that exceeded to washout accordingly. The average removal efficiency of TSS & VSS is shown in Table 5.

Sludge characteristics

The total amount of sludge in the reactor was calculated to determine the appropriate SRT to obtain high concentration of methanogenic bacteria. The daily change in the sludge amount was calculated by the mass balance between the accumulated biomass and the amount of daily biomass washed out (VSS in effluent waters). The growth characteristics were determined by the growth yield Y_g , decay constant K_d of retained sludge, as described by Syutsubo et al. [18] in Eq. (1)

$$\frac{dx}{dt} = -\left(\frac{ds}{dt}\right) Y_g - K_d \cdot X_{i-1} - \left(\frac{dx}{dt}\right)_{\text{lost},i} \quad (1)$$

where $\frac{dx}{dt}$ is the Daily biomass accumulation rate (gVSS/day), $\frac{ds}{dt}$ the Daily substrate consumption accumulation rate (gCOD/day), $\frac{dx}{dt}$ Lost the Daily biomass washout rate per reactor (gVSS/day) and (X_{i-1}) the Biomass in the reactor on day $(i-1)$ (gVSS per reactor).

As a result of fitting the 5 points, the error (r) was minimum for the growth yield $Y_g = 0.02$ gm VSS/gCOD. It was found that the growth yield Y_g was very close to that reported by Takahashi et al. [19] which was estimated by 0.029 gVSS/gCOD. While it is double the value of 0.13 gVSS/gCOD reported by Yoochatchaval et al. [8]. The decay rate was calculated to be $K_d = 0.0001$ 1/day, which was very near to the value reported by Yoochatchaval et al. [8]. The SRT was calculated accordingly and adjusted to 90 ± 10 days.

The biomass concentration profiles were obtained by the TSS and VSS concentrations taken from sampling ports at various heights of the reactor. At the time of reactor startup, VSS/TSS was 0.75. There was a stable percent of VSS/TSS ratio throughout the operation. Fig. 5 shows the sludge profile along the reactor height at the cold temperature Runs. While Fig. 6 shows the volatile solids to total solids ratio.

Denitrification

The Nitrogenous compounds were measured to examine denitrification without affecting the COD removal. Some work has shown that denitrification and methanogenesis could simultaneously occur to remove nitrogen and carbon from wastewater with high COD:P:N ratio, in which organic COD and nitrate were used as substrates [20–22]. Table 6 shows the average values for the NO_x and TP in influent and effluent waters.

The efficiencies of total nitrogen removal ranged between 2.23 and 10.83% with an apparent decrease during the low temperature stage (stages 5 & 6) where all anaerobic bacterial growth was inhibited and then decreased further more in the low temperature with high hydraulic loading i.e. very short SRT in stage 6.

Nitrite removal was in the range of (23.08–77)% with up to the 2 mg/L in the effluent water when obtaining high organic loading and warm temperature (Stage 4). The methanogenic bacteria were affected by the very low SRT that causes the denitrification bacteria to be a predominant in the reactor.

The maximum efficiency of ammonium removal reached about 13.58% at stage 4 where the HRT was in the range of

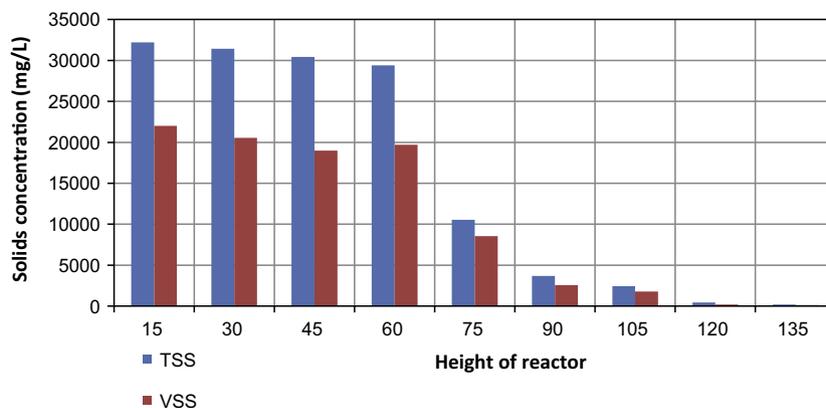


Fig. 5 Sludge profile along the reactor height.

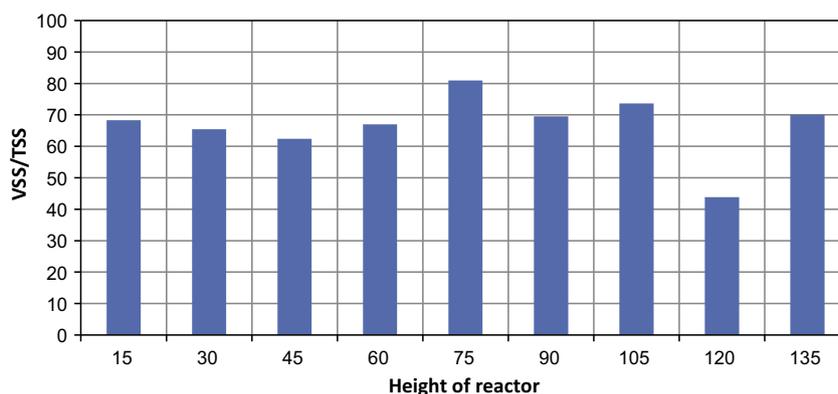


Fig. 6 Volatile Suspended solids to total suspended solids ratio along the reactor height.

Table 6 Nitrogen contents in influent and effluent waters.

Phase	TN			NH ₄ -N			NO ₃ -N			NO ₂ -N		
	inf	eff	%	inf	eff	%	inf	eff	%	inf	eff	%
(1)	–	–	–	–	–	–	–	–	–	–	–	–
(2)	58.3	57	2.2	15	14	6.7	11.5	7.5	34.8	–	–	–
(3)	–	–	–	16.5	15.4	6.6	4.4	1.9	56.8	14	9	35.7
(4)	50.8	45.3	10.8	16.2	14.0	13.6	5.40	4.20	22.2	9	2	77.8
(5)	52	48.5	6.7	41.6	40.2	3.4	3.10	1.40	54.8	11	08	23.0
(6)	47.2	45	4.6	40.6	38.4	5.4	2.50	1.50	40	–	–	–

2.5 h. This value was near the values reported by José [23]. The relatively low removal efficiency in longer retention time runs was due to the ammonification effect, where the ammonia percent in the reactor increases due to particulate-N hydrolysis and acidification.

These results demonstrated that the domestic wastewater could be anaerobically treated in a fluidized bed UASB reactor with very low HRT reaching 2 h.

Conclusion

This experiment had proven that the UASB can be used as a primary treatment unit achieving good COD removal with

very low hydraulic retention time reaching 2.5 h with removal efficiency of 38.89%.

The UASB reactor can accommodate with the low ambient temperature of and average of (14–16) °C without affecting the reactor performance in COD removal efficiency.

The UASB can be a feasible process used as a denitrification unit to remove a portion of the domestic wastewater ammonia, and denitrifying nitrate to nitrite prior to the nitrification process in aerobic unit. Decreasing the air supply required for the nitrification process.

Methane yield rate and methanogen activity were both increased with relatively high temperature. And the amount of biogas production was affected by OLR. The highest

methane yield rate was 0.285 l/gCOD total at highest temperature 19 °C. And largest amount of biogas value is 30.10 l/g COD removed/day with highest OLR 7.76 kg COD/m³/day.

The optimal feasible working temperature of UASB as per the Egyptian climate is 18–25 °C with HRT 4.0 h, OLR 2–7.7 kg COD/m³/day if not considering energy consumption and capital cost evolved in bigger UASB unit.

Conflict of interest

There is no conflict of interest.

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