ANAEROBIC BIODEGRADABILITY AND TREATMENT OF EGYPTIAN DOMESTIC SEWAGE

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ABSTRACT

The anaerobic biodegradability of domestic sewage for four Egyptian villages and four Egyptian cities was determined. The sewage of the Egyptian villages and cities represented a very strong sewage with an average total COD of 1100 and 570 mg/l, respectively. The biodegradability of the Egyptian-villages sewage (73%) was higher than that of the cities (66%). The results of a mathematical-model indicates that at applying a UASB reactor for the treatment of Egyptian villages and cities sewage, an optimum HRT of, respectively, 16 and 8 h is required. At these HRTs, a total COD removal and a conversion to methane of, respectively, 62-70% and 59-64% can be achieved for the sewage of Egyptian cities and, respectively, 71-77% and 67-69% will be obtained for the villages sewage. The model results show also that at a treatment of villages sewage in a two-step (anaerobic filter + UASB reactor) system a higher total COD removal can be achieved (77-81%) at a short HRT of 10 h (4+6 h).

KEYWORDS

ADM1; anaerobic digestion; biodegradability; domestic sewage; UASB reactor; wastewater treatment

1. INTRODUCTION

In Egypt, more than 90% of Egyptian villages are not provided with domestic-sewage treatment plants. There are about 4000 Egyptian rural-areas with a population ranged from 1000 to 20000 capita. The existing wastewater treatment plants (mainly located in the large Egyptian cities) are almost activated sludge and trickling filter systems, which suffer from a lack of money for operation and maintenance. The high construction, operation and maintenance costs of these systems represent obstacles for the Egyptian government to install sewage treatment plants in Egyptian villages.

High-rate anaerobic systems represent low-cost and sustainable technology for domestic sewage treatment, because of its low construction, operation and maintenance costs, small land requirement, low excess sludge production and biogas production. The anaerobic biodegradability (conversion to methane) is an important parameter for evaluating the potential of anaerobic treatment of any wastewater (Elmitwalli *et al.* [1]). Measuring the anaerobic biodegradability can be carried out either by batch experiments or by batch recirculation experiments (Last and Lettinga [2], Wang, [3], Elmitwalli *et al.* [1]). However, the latter method represents not only the biodegradability, but also the removal. Determining the biodegradability in batch experiments can be performed either by addition of incolumn or without. Addition of incolumn method represents inaccurate method due to the production dissolved organic matter and biogas from the decay of incolumn, while the experiment without addition of incolumn suffers from a long period for the experiment. Elmitwalli *et al.* [1] determined the anaerobic biodegradability of Dutch sewage in serum bottles for raw, paper-filtered and membrane-filtered sewage without any (additional) inoculation at 20 and 30^{o}C. They found a high and a similar anaerobic biodegradability for the raw sewage (74%) at 20 and 30^{o}C. However, at 20^{o}C, this value was reached after 135 days, while at 30°C, it took only ca. 80 days. The highest value was found for the colloidal fraction (86±3%), followed by 77±4% for the suspended fraction and only 62 % for the dissolved fraction. Last and Lettinga [2] and Wang [3] determined the maximum removal of, respectively, presettled and pretreated domestic sewage in batch recirculation experiments with granular sludge at a temperature of 20°C. Last and Lettinga [2] found that the maximum removal of total, suspended, colloidal and dissolved COD were 65, 84, 72 and 54% respectively and Wang [3] found 74, 96, 80 and 61% respectively.

This research aims at the determination of the biodegradability of Egyptian sewage. For obtaining representative results, the biodegradability was measured for four Egyptian-villages and four Egyptian-cities. Moreover, a simple mathematical-model based on the anaerobic digestion model no. 1, ADM1 (IWA [4]) was developed to determine the most suitable system configuration and its HRT for the anaerobic treatment of Egyptian sewage.

2. MATERIALS AND METHODS

The domestic sewage used in the experiments was taken from wastewater pump-stations of four cities (El-Mansoura, Aga, Sananoud and El-Senblawein) and four villages (Shawa, Meat El-Aamel, Nawasa El-Gheat and Nawasa El-Bahr). Eight plastic containers of 5 litres capacity were filled with 3.5 litres of raw sewage representing the different sources. A tap for wastewater sample collection was located on the bottom of each container. Each container was completely closed to avoid entering of air inside each container and to guarantee anaerobic conditions. The experiments were carried out at ambient temperature, which ranged between 24 and 34^{o}C. After 17, 22, 30, 36, 44, 53, 64, 86, 114 and 121 days of starting the experiments, a sample of about 40 ml was withdrawn from each container. For each sample, total and filtered COD were determined. All measurements were carried out according to *Standard Methods* (APHA, [5]).

3. RESULTS AND DISCUSSION

3.1. Characteristics and anaerobic biodegradability of the Egyptian domestic-sewage

Table 1 shows the characteristics of domestic sewage for the Egyptian cities and villages. The domestic sewage of the Egyptian villages and cities represents a very strong sewage with an average total COD of 1100 and 570 mg/l respectively. Moreover, the suspended COD represents the major part of total COD (about 70%) for the sewage of both Egyptian cities and villages.

Figure (1) represents the course of total COD for the sewage of the Egyptian cities and villages in the biodegradability experiments. The results clearly indicated that minimum total COD after anaerobic biodegradability depended on the initial total COD. Therefore, the Egyptian-cities sewage showed lower values for the minimum total COD as compared to that of villages (Table 2) and El-Mansoura city minimum total COD represented the lowest (120 mg/l). Contrary to the minimum total COD, the biodegradability of the Egyptian-villages sewage (73%) was higher than that of the cities (66%). These results are almost comparable to that found by Elmitwalli *et al.* [1] for the Dutch sewage (74%).

Table 1. Characteristics of the domestic sewage for the Egyptian cities and villages.

Parameter	Unit	Cities					Villages				
		1*	2	3	4	Average	5	6	7	8	Average
BOD_5	mg/l	164	422	392	256	309	596	708	454	434	508
COD	mg/l										
▪ Raw		346	768	653	499	567	1037	1498	998	922	1113
▪ Filtered		77	173	211	211	168	403	365	365	307	360
NH_4^+	mg/l	10	51	48	51	40	48	48	52	96	61
PO_4^{3-}	mg/l	2.0	3.1	11.4	12.1	7.1	13.0	15.7	13.0	11.7	13.4
SO_4^{2-}	mg/l	55	61	81	62	65	79.5	68.9	72.4	81.8	75.7
Cl^-	mg/l	80	405	261	162	237	441	414	306	486	412
PH		7.5	7.3	7.4	7.5	7.4	8	7.7	7.5	8	7.8

* 1:El-Mansoura, 2: Aga, 3: Sananoud, 4: El-Senblawein, 5: Shawa, 6: Meat El-Aamel, 7: Nawasa El-Gheat, 8: Nawasa El-Bahr.

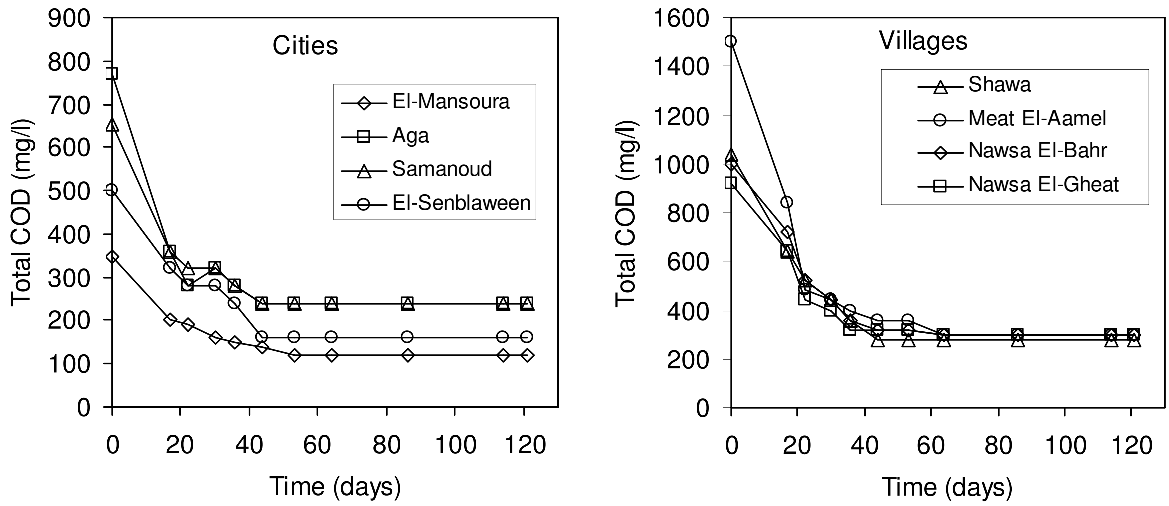

Fig.1. Course of the total COD for the sewage of the Egyptian cities and villages in the anaerobic biodegradability experiments.

Table 2. Minimum concentration and maximum anaerobic-biodegradability of the domestic sewage COD fractions for the Egyptian cities and villages.

Place	Min. COD (mg/l)			Max. biodegradability (%)		
	Total COD	Soluble COD	Suspended COD	Total COD	Soluble COD	Suspended COD
Egyptian cites:-						
▪ El-Mansoura	120	55	65	65	29	76
▪ Aga	240	100	140	69	42	77
▪ Samanoud	240	100	140	63	53	68
▪ El-Senblawein	160	80	80	68	62	72
Average (standard deviation)	190 (60)	84 (21)	106 (39)	66 (3)	46 (14)	73 (4)
Egyptian villages:-						
▪ Shawa	280	100	180	73	75	72
▪ Meat El-Aamel	300	120	180	80	67	84
▪ Nawsa El-Bahr	300	100	200	70	73	68
▪ Nawsa El-Gheat	300	120	180	67	61	70
Average (standard deviation)	295 (10)	110 (12)	185 (10)	73 (5)	69 (6)	74 (7)

The results showed that the minimum suspended COD after anaerobic biodegradability was lower for the sewage of the Egyptian cities as compared to that of the Egyptian villages (Table 2). However, the biodegradability of the suspended COD was similar for both villages and cities (73-74%) and slightly lower than that of Dutch sewage, 77%, (Elmitwalli *et al.*[1]). The minimum soluble COD after the anaerobic biodegradability was slightly lower for the Egyptian-cities sewage as compared to that of villages (Table 2) and also El-Mansoura city minimum soluble COD represents the lowest (55 mg/l). However, the biodegradability of the soluble COD for villages sewage (69 %) was significantly higher than that for the cities (46 %). This was the reason for the higher anaerobic biodegradability of the total COD for the Egyptian-villages sewage as compared to that of cities, as the biodegradability of suspended COD was similar for both villages and cities. The biodegradability of soluble COD for both Egyptian villages and cities was in the range found by Last and Lettinga [2] and Elmitwalli *et al.* [1], 54 and 62 % respectively

3.2. Application of high-rate anaerobic systems for the treatment of Egyptian sewage

The results showed that the sewage of the Egyptian villages and cities represents a very strong sewage. Therefore, at application of aerobic systems for the treatment of Egyptian sewage, especially for villages sewage, a long HRT and high oxygen requirement for aeration are needed, which will result in high investment, operation and maintenance costs. The high total COD concentration for Egyptian-villages sewage is not due to the low water consumption, as about 94% of Egyptian rural-areas have a water supply. Elmitwalli [6] mentioned that the high total COD concentration in Egyptian rural-areas is mainly due to the illegal discharge of cow manure in the gravity sewers by the farmers. The high-rate anaerobic systems can represents a suitable solution for the treatment of Egyptian sewage and the high anaerobic biodegradability (65-80 %) of Egyptian sewage confirms the high potential of the application of anaerobic treatment. The upflow anaerobic sludge blanket (UASB) reactor is the most widely and successfully used high-rate anaerobic systems for the treatment of several types of wastewaters (Lettinga *et al.*, [7]). Moreover, Elmitwalli *et al.* [8, 9, 10, 11 and 12] found that addition of filter media in the top of the UASB reactor (i.e. anaerobic hybrid, AH, reactor) improved the removal of colloidal particles in sewage.

As the suspended COD after biodegradability experiments can be separated by settling, the soluble COD at the end of biodegradability experiments can be considered as the minimum COD after anaerobic process. The results showed that the minimum COD after anaerobic process for Egyptian villages and cities (84 and 110 mg/l respectively) is higher than of Egyptian effluent standard (80 mg COD/l) for the discharge of the treated sewage to the Egyptian drains. Therefore, post treatment is needed, which should be like the anaerobic pre-treatment, a high-rate, low-cost and sustainable technology. As the anaerobic effluent has a low COD concentration, Elmitwalli *et al.* [13] found that a trickling filter with vertical sheets of reticulated polyurethane-foam and without wastewater recirculation was an efficient post-treatment system for domestic sewage at hydraulic loading rate of 15 $m^3/m^2/d$. Such trickling filter represents a high-rate system with low construction, operation and maintenance costs, as it can be operated by gravity without wastewater recirculation.

Application of a two-step system might be more suitable for the anaerobic treatment of concentrated sewage, like the sewage of Egyptian villages, than a one step (Zeeman and Lettinga, [14]). The first-step is aimed at removal and partial hydrolysis of suspended COD and the second-step mainly for conversion of dissolved COD to methane. Wang [3] and Elmitwalli *et al.* [15] developed, respectively, a high-loaded UASB and anaerobic filter (AF) for the first step. They found that their first step had a higher COD removal as compared to the primary sedimentation tank and by using an AF reactor the highest removal efficiency was achieved for suspended COD. As the Egyptian cities have a lower total COD (570 mg/l) as compared to the Egyptian villages, application of a one-step UASB (or AH) reactor will be sufficient for the treatment of cities sewage.

3.3. Mathematical modelling for the anaerobic treatment of Egyptian domestic sewage

A simple mathematical-model based on ADM1 (IWA, [4]) was developed for obtaining the most suitable system configuration and HRT for the anaerobic treatment of Egyptian sewage. For simplification and reduction of constants assumption, the model is mainly based on first-order and Monod kinetics for, respectively, hydrolysis of biodegradable particulate and conversion of dissolved organic matter. Table 3 shows biochemical rate coefficients and kinetic rate equations for particulate and soluble components.

Table 3. Biochemical rate coefficients and kinetic rate equations for particulate and soluble components in the model.

Component (*i*)→	X_b	X_i	X_m	S_b	S_{CH4}	S_i	Rate
Process (*j*) ↓							
Hydrolysis	-1			1			$K_{hyd} * X_b$
Conversion			Y_m	-1	$(1-Y_m)$		$K_m * S_b * X_m / (K_s + S_b)$
Decay	1		-1				$K_d * X_m$

X_b: biodegradable-particulate concentration (mgCOD/l), X_i: inert-particulate concentration (mgCOD/l), X_m: biomass concentration (mgCOD/l), S_b: biodegradable soluble-substrate concentration (mgCOD/l), S_{CH4}: converted substrate to methane (mg CH_4-COD/l), S_i: soluble-inert concentration (mgCOD/l), K_{hyd}: first-order hydrolysis constant (1/d), K_m: Monod maximum specific uptake rate (mg COD_S/mg COD_X.d), K_s: half saturation concentration (mg COD/l), Y: yield of biomass on substrate ((mg COD_S/mg COD_X), μ_{max}: Monod maximum specific growth rate (1/d).

For the treatment of Egyptian cities sewage, a one-step UASB (or AH) reactor was studied in the model, while for the sewage of the Egyptian villages both one and two step systems were studied. The first-step of the two-step system was assumed to be either AF or high-loaded UASB reactor and the second-step is a UASB (or AH) reactor. Based on the results obtained by Elmitwalli *et al.* [11], the removal of suspended and soluble COD and methanogenesis in the first-step of the two-step were assumed to be 60, 15 and 15% respectively. Each reactor is considered as a completely stirred tank reactor. Also, in the model, the effluent particulate concentration is assumed to originate from the influent (i.e. not removed in the reactor) and having a retention time equal to the reactor HRT. Therefore, the mass balance for particulate organic can be written as follow:-

$$\frac{dX_i}{dt} = \frac{qX_{influent,i}}{V} - \frac{qX_{influent,i}(1-R)}{V} + \sum_{j=1-3} rate\ coefficient * kinetic\ rate\ equation$$

Where q, V and R are wastewater flow (l/d), reactor volume (l) and particulate removal respectively. Table 4 shows the values of constants and variables applied in the model. The reactor was assumed to start without seed sludge addition and the sludge is allowed to accumulate in the reactor until it reaches 65% of the reactor volume. Thereafter, the sludge wastage will be started. The model was carried out applying numerical integration at small time interval of 0.005 day (i.e. 7.2 minutes).

Table 4. Values of parameters and variables applied in the model.

							References
Wastewater concentration:	X_b	X_I	X_m	S_b	S_I		This study, Elmitwalli *et al.* [4]
Cities (COD_t=600 mg/l)	365	18	37	117	63		
Villages:-							
COD = 1150 mg/l*	700	25	75	265	85		
COD =620 mg/l**	280	10	30	215	85		
Kinetic parameters:	Y	K_d	K_s	μ_{max}	K_{hyd}		This study, Pavlostathis and Giraldo-Gomes [16], IWA [4]
Temperature (°C) 18	0.1	0.02	400	0.15	0.15		
28	0.1	0.02	200	0.25	0.30		
Operational parameters	Cities		Villages*		Villages**		
	18°C	28°C	18°C	28°C	18°C	28°C	This study, Wang [3], Elmitwalli *et al.* [12], Mahmoud [17]
Suspended COD removal (%)	70	75	75	80	60	65	
Sludge bed conc. (gCOD/l)	35	35	35	35	40	40	

* sewage will be treated in a one-step system, ** sewage will be treated in a two-step system and the mentioned values for the second step.

In the treatment of the cities sewage, the mathematical model results show that the reactor needs a long period for achieving the required sludge bed concentration (Fig. 2.A) mainly due to the slowly growth rate of the anaerobic biomass. For example at HRT of 8 h at 28°C, the period is 195 days. However, this period can not be considered as a start-up period, as the system achieves a stable effluent quality and methane production in a shorter period (Fig. 2.A). The required sludge-bed concentration in the UASB (or AH) reactor is needed not only for achieving a higher conversion, but also for improvement of the biophysical removal of sewage particulate in the sludge bed. Fig. (2.B) shows, for example, the performance of the reactor in the anaerobic treatment of Egyptian-cities sewage at HRT of 8 h at 18°C (winter period) and 28°C (summer period). Although the reactor needs an operational period of 6.5 months to achieve the sludge bed concentration at HRT of 8 h at

28°C, the effluent quality and biogas production reaches to a stable value after only 3 months (Fig. 2.B). Fig. 3 shows the performance of the UASB (or AH) reactor in the treatment of Egyptian-cities sewage at different HRTs at 18 and 28°C, when the reactor reaches steady state. The results clearly showed at HRT of 8 h or higher, the reactor achieves the optimum operation conditions. Therefore, 8 h represents the minimum and the best HRT for the treatment of Egyptian-cities sewage (in summer and winter) in a one-step UASB (or AH) reactor. At such HRT, effluent COD concentration, total COD removal and methanogenesis of, respectively, 182 mg/l, 70% and 64% can be achieved at 28°C and, respectively, 230 mg/l, 62% and 59% at 18°C. Moreover, the excess sludge represents only 3-6% of the influent total COD with 21-29% biodegradable fraction.

The mathematical model results for the application of a one-step UASB (or AH) reactor for the treatment of the domestic sewage of the Egyptian villages show that a shorter period is needed for achieving a stable effluent quality (Fig. 4.A) as compared to that of the cities (Fig. 2.A). Moreover, higher total-COD removal efficiency and methanogenesis can be achieved at treatment of villages' sewage (Fig. 4.B). However, a longer HRT is needed. The results clearly demonstrated that the minimum and the best HRT for a UASB (or AH) reactor treating Egyptian-villages sewage is 16 h. Increasing HRT more than 16 h only slightly improves the digestion of the biodegradable fraction in the sludge. At HRT of 16 h, effluent COD concentration, total COD removal and methanogenesis of, respectively, 262 mg/l, 77% and 69% can be achieved at 28°C and, respectively, 331 mg/l, 71% and 67% at 18°C. Moreover, the excess sludge represents only 4-8 % of the influent total COD with 26-35% biodegradable fraction.

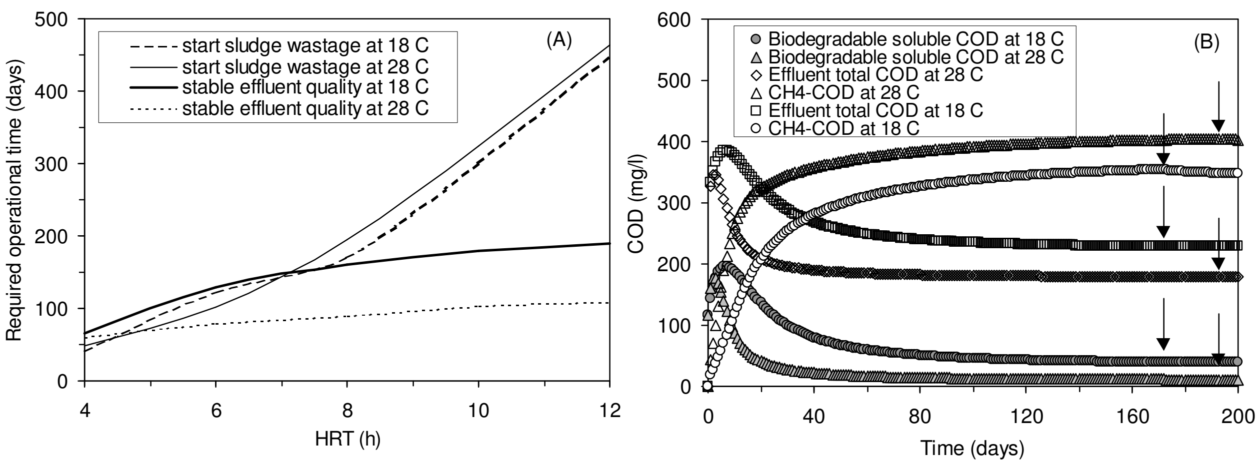

Fig. 2. Required operational time for achieving sludge bed concentration and stable effluent quality (A), and the performance of the UASB (or AH) reactor in the start-up period at HRT of 8 h (B) at 18 and 28°C for the treatment of Egyptian-cities sewage. (↓) Start of sludge wastage.

In the treatment of villages sewage in a two-step system, the results of the mathematical model shows that the second-step (UASB or AH reactor) needs long period to achieve a stable effluent quality (Fig. 5. A), which indicate the need of a small amount of seed sludge to reduce this period. The results clearly show that the second-step can be operated at a short HRT as low as 6 h without affecting on the removal efficiency (Fig. 5. B). Decreasing HRT to be lower than 6 h, may affect on the particulate COD removal. Therefore, the suitable HRT for the second-step is 6 h. Accordingly, the overall HRT of the two-step system will be 10

(4+6) h, as Elmitwalli *et al.* [11] found that the suitable HRT for the AF (as a first-step) reactor treating raw sewage at 13°C was 4 h. At such HRT for the two-step, effluent COD concentration, overall total COD removal and overall methanogenesis of, respectively, 214 mg/l, 81% and 48% can be achieved at 28°C, and, respectively, 260 mg/l, 77% and 45% at 18°C. Moreover, the overall excess sludge represents 32% of the influent total COD. The excess sludge from the first-step of the two step system represents the major part of the excess sludge from the system (31% of the influent total COD). The results clearly demonstrated that by application of the two-step system for the treatment of the Egyptian-villages sewage, a higher total COD removal (77-81%) can be obtained at lower HRT (10 h) as compared to the application of a one-step system (16 h). However, the overall methanogenesis (conversion to methane) is higher by applying a one step system, as the excess sludge from the first-step is not a stabilised sludge. Because there is no regulation in Egypt for the characteristic of the excess sludge, digestion of the excess sludge from the first-step of the two-step system is not needed (existing activated sludge treatment plant in Egyptian cities had no sludge digester, except Cairo plant). Therefore, the main disadvantage for the treatment of the Egyptian sewage in a two-step system as compared to a one step system is that more control in the frequently of sludge wastage from the first step of the two-step system is required.

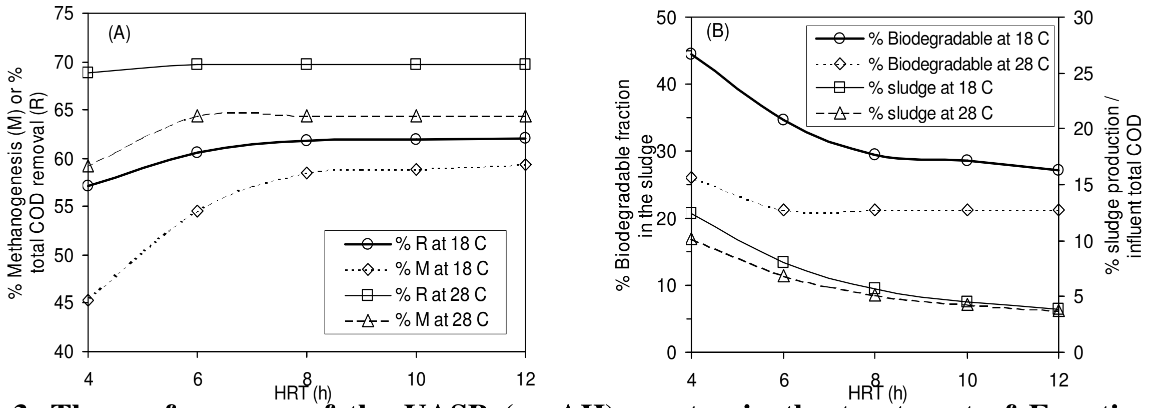

Fig. 3. The performance of the UASB (or AH) reactor in the treatment of Egyptian-cities sewage at different HRTs at 18 and 28°C, when the reactor reaches steady state.

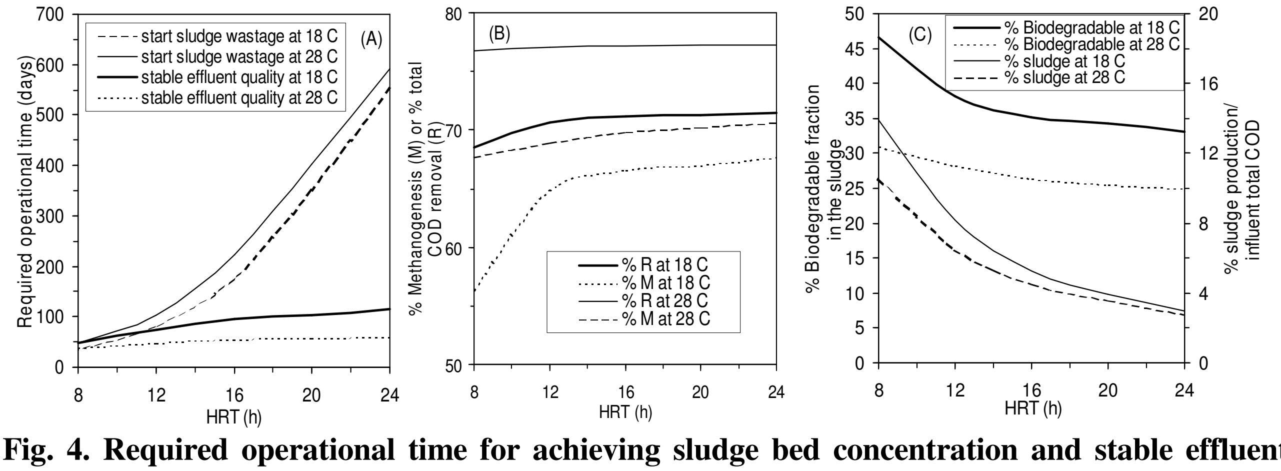

Fig. 4. Required operational time for achieving sludge bed concentration and stable effluent quality reactor in the treatment of Egyptian-villages sewage in a UASB (or AH) reactor at different HRTs at 18 and 28°C (A), and the performance of the reactor, when it reaches steady state (B, C).

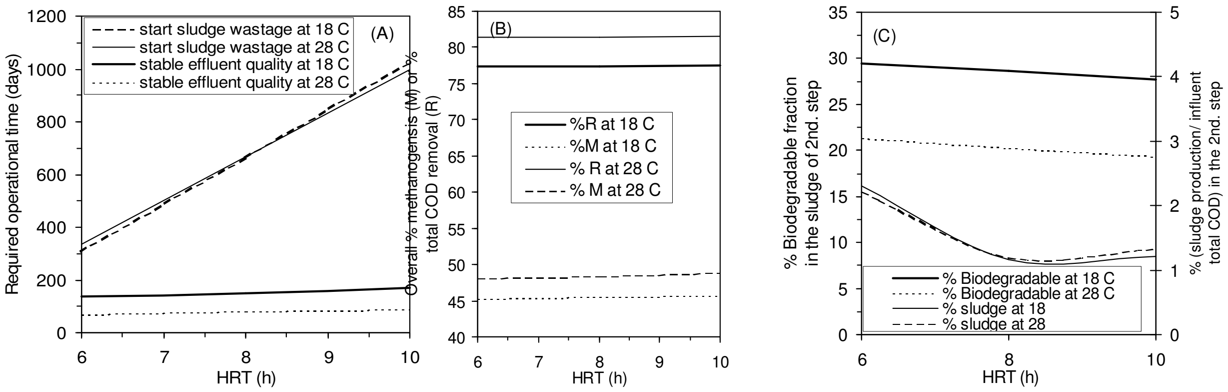

Fig. 5.. Required operational time for achieving sludge bed concentration and stable effluent quality in the treatment of the Egyptian-villages sewage in the second-step of the two-step system at different HRTs at 18 and 28°C (A), and the performance of the system, when the reactor reaches steady state (B, C).

4. CONCLUSIONS

1. The sewage of the Egyptian villages and cities represented a very strong sewage with an average total COD of 1100 and 570 mg/l respectively.
2. The anaerobic biodegradability of the Egyptian-villages sewage (73%) was higher than that of the cities (66%). The higher biodegradability of the soluble COD for Egyptian-villages sewage (69 %) as compared to that of the cities (46 %) was the reason for the higher biodegradability of total COD for the villages sewage.
3. The result of the mathematical-model shows that an optimum HRT of 16 and 8 h is required at applying a UASB (or AH) reactor for the treatment of the sewage of Egyptian villages and cities respectively. At these HRTs, a total COD removal and conversion to methane of, respectively, 62-70% and 59-64% can be achieved for the sewage of Egyptian cities and, respectively, 71-77% and 67-69% will be obtained for the sewage of the Egyptian villages.
4. The model results shows also that at a treatment of the villages domestic sewage in a two-step (anaerobic filter + UASB (or anaerobic hybrid) reactor) system a higher COD removal can be achieved (77-81%) at a shorter HRT of 10 h (4+6 h). However, the excess sludge from the first-step of the two-step system was less stabilised as compared to that of a one-step system.

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