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Determination of design criteria for UASB reactors as a wastewater pretreatment system in tropical small communities

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Abstract

A pilot scale study was set up to investigate the principle design parameters of up flow anaerobic sludge blanket (UASB) reactors for treating wastewater of small communities in the tropical regions of Iran. A steel pipe with a diameter of 600 mm and a height of 3.6 m was used as the reactor in which a digestion and a 3-phase separator element had a volume of 0.848 and 0.17 m^3 respectively. During this study, which lasted for 203 days, two distinct phases were carried out according to the ambient temperature. The temperature of the wastewater entering the reactor was naturally ranged from 22 to 26 ^{0}C and no heat exchanger was used. The hydraulic retention times including 2, 4, 6, 8, and 10 hours with various loading rates of 0.95 to 5.70 kg COD/m^3/day for colder period and from 1.35 to 6.40 kg COD/m^3/day for warmer period were examined. On the basis of the results the optimal hydraulic retention time for warmer period with a 2.20 kg COD/m^3/day organic loading rate was 6 hours which BOD5, COD and TSS removal efficiency were 71, 63 and 65 percent respectively. During the colder period the removal ratio of BOD5, COD and TSS with an optimal hydraulic retention time of 8 hours and organic loading rate of 1.22 kg COD/m^3/day were 54, 46 and 53 percent respectively.

Key words: *UASB reactor, HRT, small communities, wastewater pretreatment, tropical regions*

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Introduction

In recent years there has been a growing interest in anaerobic treatment of wastewaters. Compared to aerobic growth, anaerobic fermentation produces much less biomass from the same amount of COD removal (Tchobanoglous, *et al.*, 1991). Upflow anaerobic sludge blanket (UASB) reactor is a popular anaerobic reactor for both high and low temperature (Dinsdale, *et al.*, 1997). The UASB reactor is by far the most widely used high rate anaerobic system for anaerobic sewage treatment. In the case of a relatively low strength wastewater such as sewage, the hydraulic retention time rather than organic loading rate is the most important parameter determining the shape and the size of the UASB reactor. The several favorable characteristics of anaerobic processes, such as low cost, operational simplicity, low biosolids production and considerable biogas production, together with suitable environmental conditions have contributed to highlight anaerobic systems for the treatment of sewage in small communities of tropical regions. Although different types of anaerobic treatment systems have been applied to a great variety of industrial wastes, so far the anaerobic treatment concept is rarely used for sewage. Experimental results of anaerobic sewage treatment are restricted to the use of the anaerobic filter, fluidized and expanded bed and the UASB with and without a three-phase separator. To compare the different anaerobic treatment systems, the UASB concept looks the most attractive option for sewage treatment (Van Haandel and Lettinga, 1994). The present work evaluates an important design parameter for a UASB reactor, that is, Hydraulic Retention Time (HRT). The performance of a UASB reactor was assessed by applying various hydraulic retention times. This research was carried out to study the feasibility of UASB process as a pretreatment alternative for Ahwaz sewage treatment. This city is located in tropical region of Iran, where in general the ambient and wastewater temperature is appropriate for anaerobic process application.

Materials and Methods

The UASB reactor used in this study was made with a pipe of 600 mm inner diameter, a total height of 3.6 m and a total volume of 1 m^3 (1000l), of which approximately 17 and 83 percent were set up as gas/solid/liquid separation and digestion, respectively. This reactor was fed with raw wastewater taken downstream from the screening unit of the Ahwaz Wastewater Treatment Plant. Because of the fluctuations in pumping station of the plant, maintenance of constant flow rates with pumps was almost impossible; therefore, an intermediate tank was used to pump the wastewater to the reactor. In order to develop the desired hydraulic retention times, the influent flow rate to the reactor was changed. Following each change in the HRT the reactor was allowed to reach steady state. The wastewater was introduced at the bottom of the reactor though a tube with a 50 mm diameter and distributed over the cross-section by means of a perforated plexiglass plate, which was placed about 40 cm above the feed tube. A tap was placed at the bottom of the reactor to remove the accumulated solids. Sample ports were placed at 0.5 m intervals throughout the height of digestion zone with an additional port at the bottom of the reactor (the port used for solids removal). In order to investigate the various HRTs effect on the efficiency of UASB, this study was divided into two phases including cold (November to February, 2001) and warm (July to September, 2002) periods. The performance of the reactor was monitored through 24-hour flow weighted composite samples, taken from inlet and sample ports. In other words, the amount of each individual sample that is added to the total mixture was proportional to the wastewater flow at the time the sample was taken. The daily samples were frozen and at the end of each week the samples were melted and mixed and the analysis were performed. The analyses included 5-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and alkalinity. It should be mentioned that the average wastewater temperature and pH were monitored daily. All the analyses were carried out according to the Standard Methods (APHA *et al*., 1995). Table 1 provides the flow rate and upflow velocity of the influent wastewater into the reactor in the various hydraulic retention times.

Results

Figure 1 shows the wastewater temperature throughout the study. The results indicated that wastewater temperature in warm and cold periods ranged from 22-26 ^{0}C and 20-22 ^{0}C, respectively. As indicated in Table 2, the UASB reactor was exposed to various HRTs including 10, 8, 6, 4, and 2 h. In the experiments carried out with the UASB reactor, the optimum HRT in terms of BOD_5 and COD removal was 6 h in which the organic load applied to the reactor was 2.20 kg COD/m^3.d and 1.14 BOD_5/m^3.d, producing a removal efficiency of 71% (BOD_5) and 63% (COD). The optimum TSS removal efficiency (61%) occurred in an HRT of 4 h in which the suspended solids loading was 2.26 kg TSS/m^3.d (Figure 2). The same HRTs were experienced for cold period (Table 2). At this time, the optimum BOD_5 and COD removal efficiency occurred in an HRT of 8 h in which the organic loading was 1.22 kg COD/m^3.d and 0.65 kg BOD_5/m^3.d. As indicated in Fig.3, the UASB reactor performance in comparison with warm period was significantly lower, with removal efficiency reaching 54% (BOD_5) and 46% (COD). Although the optimum HRT for TSS removal was similar to the warm period, that is, 4 h, the reactor performance in TSS removal (45% for suspended solids with a loading of 1.67 kg TSS/m^3.d) was again lower in comparison to warm period.

Discussion

Influence of temperature

As indicated in Figure 2 and 3, in a same HRT the increase in wastewater average temperature from 21 to 24 ^{0}C increased the BOD_5 and COD removal efficiency. This result is in agreement with the earlier work of De Man, 1990 and Kennedy *et al.*, 1981.This is also true for TSS removal efficiency because in a same HRT an increase in wastewater temperature from 21 to 24 ^{0}C increased the removal performance of the UASB reactor. The increase in the removal efficiency can probably be attributed to a high rate of hydrolysis of organic matter by microorganisms; or to the decrease of viscosity and consequently increase of settling velocity.

Table 1: The characteristics of the influent wastewater

Period	Week	HRT	BOD	COD	TSS	Period	Week	HRT	BOD	COD	TSS
Cold	1	2	211	431	276	Warm	18	2	252	485	299
	2		210	417	265		19		251	485	312
	3		220	399	263		20		253	487	328
	4		227	401	261		Mean±SD		252±1	485.7±1.15	313±14.53
	Mean±SD*		213.7±8.04	415.7±15.01	268±6.70		Range		251-253	485-487	299-328
	Range		210-227	399-431	261-276		21	4	251	484	338
	5	4	215	408	253		22		256	493	343
	6		207	394	244		Mean±SD		253.5±3.54	488.5±6.36	340.5±3.54
	7		204	386	230		Range		251-256	484-493	338-343
	Mean±SD		208.7±5.69	396±11.14	242.3±11.59		23	6	256	493	343
	Range		204-215	386-408	230-253		24		260	501	350
	8	6	191	362	223		Mean±SD		258±2.83	497±5.66	346.5±4.95
	9		191	363	238		Range		256-260	493-501	343-350
	10		197	373	230		25	8	260	502	351
	11		198	375	212		26		260	501	353
	Mean±SD		194.3±3.77	368.3±6.70	225.8±11.03		Mean±SD		260±0	501.5±0.71	352±1.41
	Range		191-198	362-375	212-238		Range		260	501-502	351-353
	12	8	195	370	211		27	10	265	510	356
	13		197	375	227		28		263	506	353
	14		199	378	241		Mean±SD		264±1.41	508±2.83	354.5±2.12
	Mean±SD		197±2	374.3±4.04	226.3±15.01		Range		263-265	506-510	353-356
	Range		195-199	370-378	211-241						
	15	10	199	379	235						
	16		197	373	234						
	17		192	365	225						
	Mean±SD		196±3.61	372.3±7.02	231.3±5.51						
	Range		192-199	365-379	225-235						

*Mean± Standard Deviation

Influence of HRT

It is observed (Figure 2) that the UASB reactor for BOD_5 and COD removal efficiency increases with increasing HRT from 2 to 10 h. However, the results indicate that there is little benefit in operating the reactor at an HRT exceeding 8 h in cold period (T= 20-22 ^{0}C) and 6 h in warm period (T= 22-26 ^{0}C) because little additional removal of BOD_5 and COD was achieved. Therefore, the optimum HRT for BOD_5 and COD removal can be considered 6 and 8 h for warm and cold period, respectively. Other studies (Haskoning and Euroconsult, 1990; Vieira and Garcia, 1991; Van Haandel and Lettinga, 1994; Yu *et al.*, 2000) are in good agreement with the result presented here. Low BOD_5 and COD removal efficiency in HRTs less than 6 h is probably owing to the less stabilized character of the sludge resulting in a stronger tendency for flotation (Van Haandel and Lettinga, 1994). Also, further increase in HRT above 6 h did not lead to a significant increase in BOD_5 and COD removal efficiency. This is probably attributed to the fact that a long HRT above 6 h might lead to a low concentration of fermentative substrates (Yu *et al.*, 2000). In addition, the study conducted by Yu *et al*. (2000), showed that in thermophilic conditions of UASB reactor the sludge bed, blanket solution and effluent had a maximum ATP concentration (biological activity) around an HRT of 5 h. As a consequence, further increase or decrease of HRT from 5 h will result in decrease of ATP concentration; thus, it might be expected that in thermophilic conditions (T= 45-55 ^{0}C) the optimum HRT is about 5 h. Based on the results (Figure 2 and 3), an increase in HRT from 2 to 10 h increased TSS removal efficiency; however, the optimum HRT for TSS removal is about 4 h. The low efficiency of TSS removal in short HRTs is due to excessive turbulence in the UASB reactor; therefore, the likelihood of entrapping suspended and colloidal solids is reduced. On the other hand, little additional removal of suspended solids at an HRT longer than 6 h is attributed to the low suspended solids concentrations remained at higher HRTs.

Simultaneous influence of temperature, HRT and organic Loading

Removal performance of the UASB reactor in terms of BOD_5, COD and TSS depends on temperature, HRT and organic loading rate (Table 2). On the basis of the obtained results, the maximum removal of BOD_5 (75%), COD (65%) and TSS (73%) with an organic loading of 1.35 kg COD/m^3.d, 0.70 kg BOD_5/m^3.d and 2.50 kg TSS/m^2.d occurred at an HRT of 10 h in warm period. Increasing the HRT from 6 to 10 h resulted only in 4, 2 and 8 percent additional removal of BOD_5, COD and TSS respectively; therefore, construction of the UASB reactor with an HRT exceeding 6 h will not be economical for an incoming wastewater with a temperature range of 22 to 26 ^{0}C. Since wastewater treatment plant design is based on critical conditions (cold period) it is more rational to choose 8 h as a design HRT and 1.22 kg COD/m^3.d or 0.65 kg BOD_5/m^3.d as a design organic loading for the UASB reactor. Consequently, the removal efficiency in terms of BOD_5 and COD in warm period will be 19 and 17 percent higher than cold period. It should be noted that although the optimum HRT for TSS removal is 4 h (61% for warm and 45% for cold periods), selection of an HRT of 8 h as a design HRT would increase TSS removal up to 71 and 53 percent in warm and cold periods, respectively.

Conclusion

The results obtained in this research demonstrated that the UASB reactor could be used as an effective pretreatment alternative for municipal wastewater in tropical regions. From the data presented here the following conclusions can be drawn:

- During the warm period, which the wastewater temperature varied from 22 to 26 ^{0}C, the optimum HRT in the UASB reactor with an organic loading of 2.20 kg COD/m^3.d and 1.14 kg BOD5/m^3.d was 6 h. The removal efficiency for BOD5 and COD was 71 and 63 percent, respectively.
- During the cold period, which the wastewater temperature was in the range of 20 to 22 ^{0}C, the optimum HRT in the UASB reactor with an organic loading of 1.22 kg COD/m^3.d and 0.65 kg BOD5/m^3.d was 6 h. The removal efficiency for BOD5 and COD was 54 and 46 percent, respectively.
- Applying a suspended solids loading of 4.21 kg TSS/m^2.d (cold period) and 5.96 kg TSS/m^2.d (warm period), the UASB performance with an optimum HRT of 4 h for TSS removal was 61 and 45 percent for warm and cold periods, respectively.

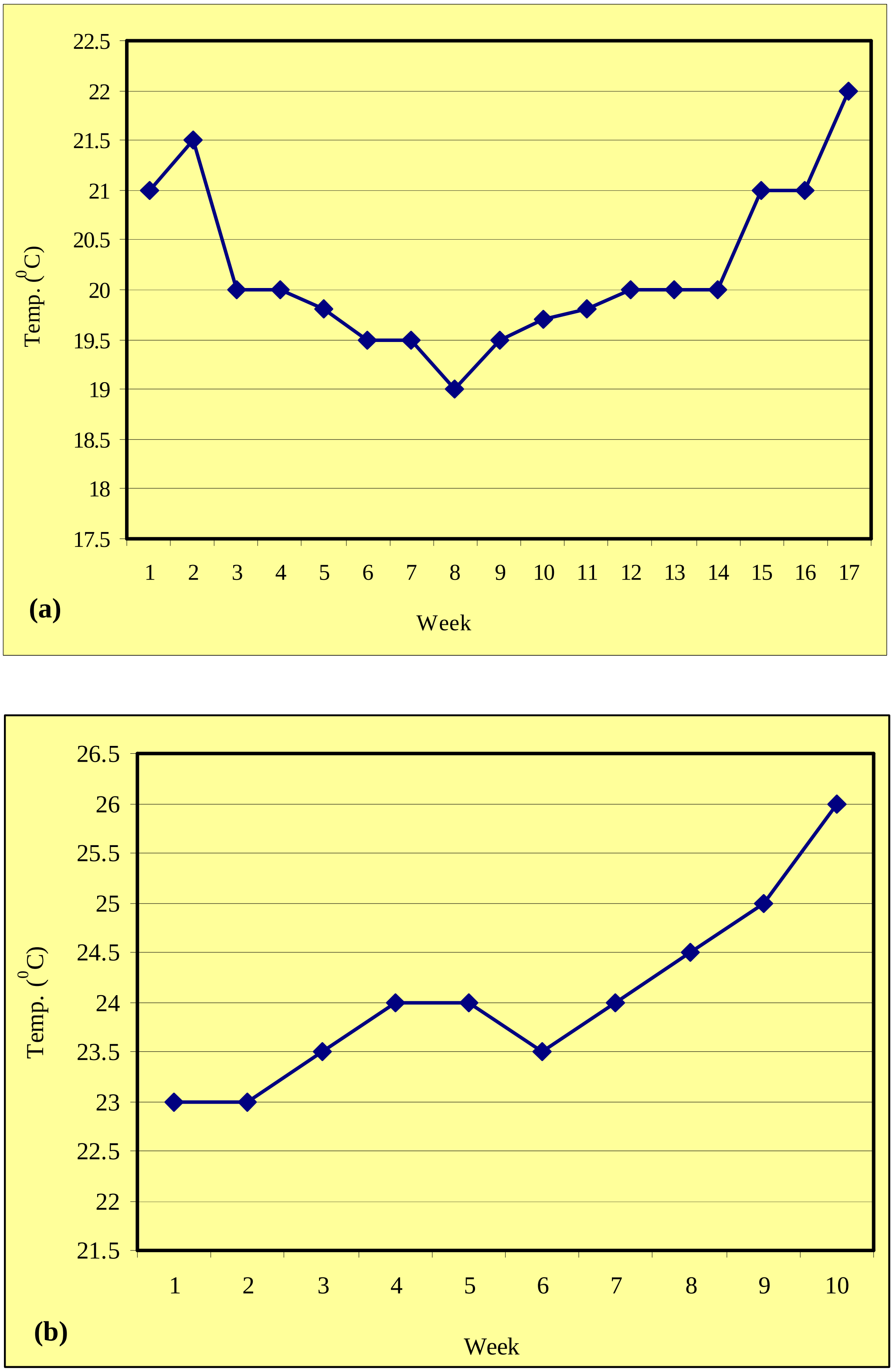

Figure 1: Variations of wastewater temperature in (a) cold and (b) warm periods

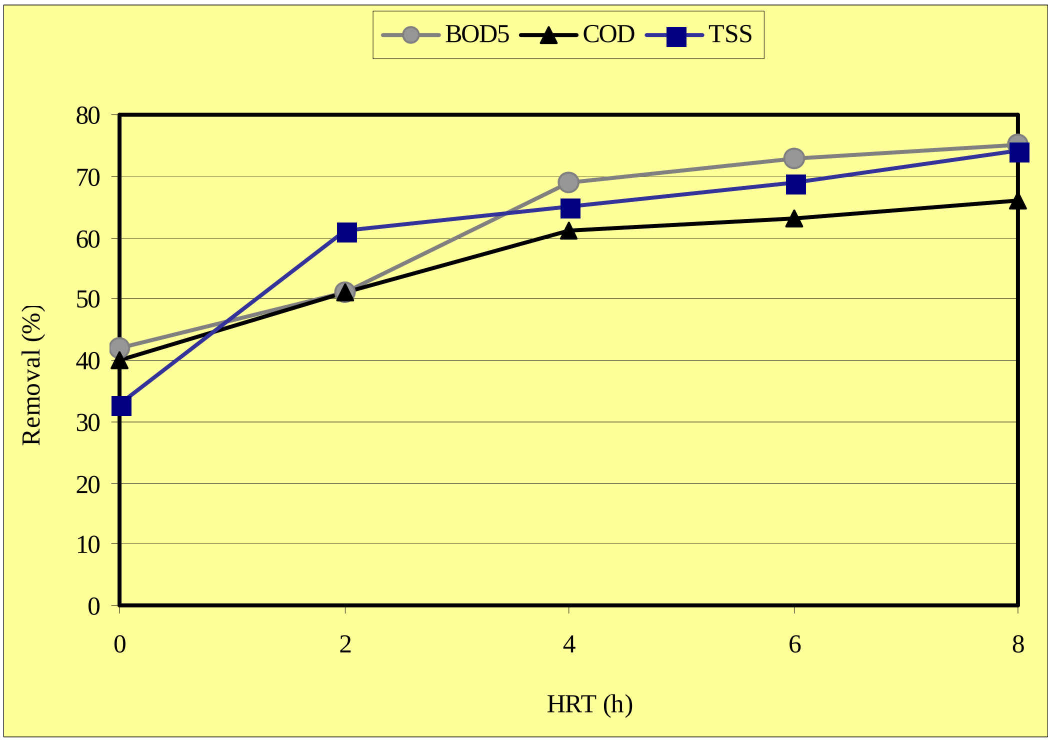

Figure 2: Average COD, BOD_5 and TSS removal percentage with hydraulic retention time in warm period

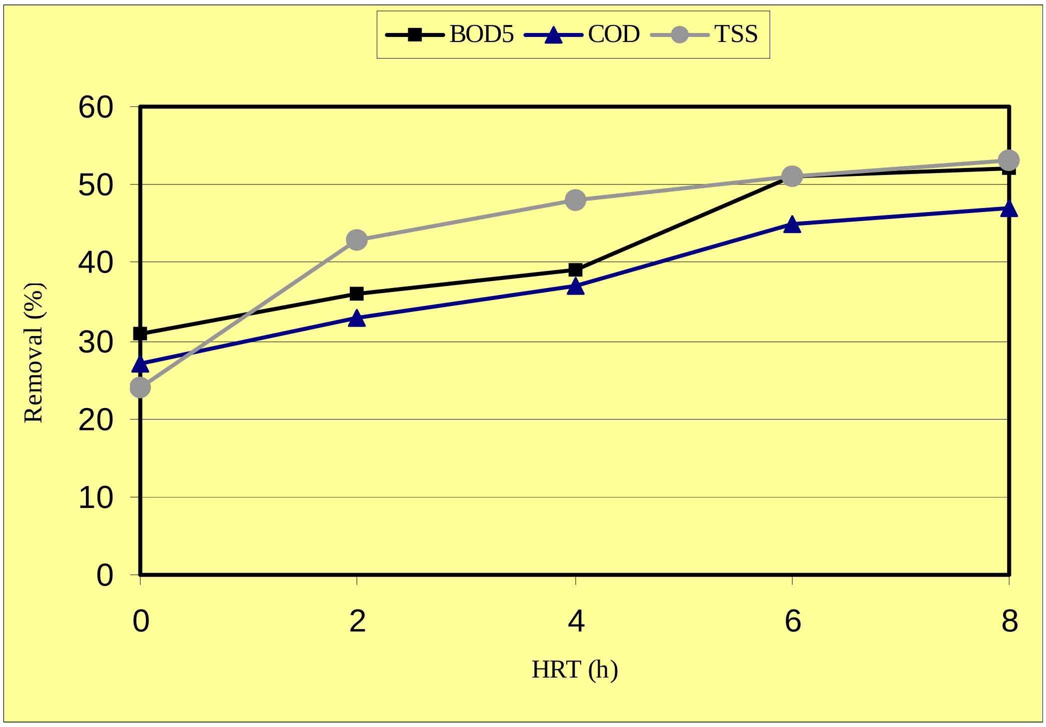

Figure 3: Average COD, BOD_5 and TSS removal percentage with hydraulic retention time in cold period

Table 2: Operational conditions in the UASB reactor

Period	Week	HRT (h)	Organic Loading (kg/m^3.d)		Removal Ratio (%)		
			BOD	COD	BOD	COD	TSS
Cold	1	2	3.00	5.70	35	29	25
	2		2.90	5.51	32	27	23
	3		2.77	5.27	28	25	22
	4		2.78	5.30	27	22	22
	5	4	1.15	2.70	39	35	45
	6		1.36	2.60	34	32	43
	7		1.34	2.54	31	28	41
	8	6	0.84	1.60	43	38	48
	9		0.84	1.60	39	37	48
	10		0.86	1.64	35	35	47
	11		0.87	1.65	36	34	44
	12	8	0.64	1.22	54	46	53
	13		0.65	1.23	50	44	51
	14		0.65	1.24	49	44	47
	15	10	0.52	1.00	56	49	55
	16		0.52	0.98	49	47	54
	17		0.50	0.96	48	44	51
Warm	18	2	3.33	6.41	39	35	29
	19		3.31	6.41	41	38	34
	20		3.34	6.43	48	45	36
	21	4	1.65	3.20	50	49	59
	22		1.70	3.25	54	52	61
	23	6	1.12	2.17	66	57	64
	24		1.15	2.20	71	63	65
	25	8	0.85	1.65	73	64	68
	26		0.85	1.65	73	64	71
	27	10	0.71	1.35	74	65	71
	28		0.70	1.34	75	65	73

- For designing a UASB reactor in tropical regions (wastewater temperature ranged from 20 to 26 ^{0}C) it is recommended to choose: HRŦ8 h; Organic Loading=1.22 kg COD/m^3.d or 0.65 kg BOD5/m^3.d.

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