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ANAEROBIC TREATMENT FOR SANA'A WASTEWATER USING UASB REACTOR PILOT PLANT

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ABSTRACT

The water scarcity in Sana'a the capital of Yemen, has resulted in the increase of the concentration of organic matter in wastewater reaching the treatment plant. The organic load in Sana'a Wastewater Treatment Plant exceeds 1100 mg/l and makes the treatment process expensive. The UASB (Upflow anaerobic sludge blanket) reactor is an anaerobic wastewater treatment system which reduces the high concentration of organic matter in wastewater and produces methane gas that can be used as solution. The aim of this research is to study the efficiency of anaerobic treatment to reduce the high COD (Chemical oxygen demand) concentrations of Sana'a wastewater using the UASB reactor. A UASB reactor was designed and constructed from galvanized iron and installed as a pilot plant representing the primary and part of the secondary stage at the Sana'a WWTP site. The UASB reactor was operated for a period of 83 days; the first period of 45 days was the application of constant flow of 23.46 l/h at Hydraulic Retention Time (HRT) of 24 hours in order to reach a steady state and allowed to run for a second period of 38 days from August 8th to September 14th, 2009. Three different HRTs were applied at 24, 12 and 6 hours, which resulted in three up flow velocities in the reactor of 0.073 m/h, 0.146 m/h and 0.292 m/h, respectively. 23 samples of wastewater were collected from the influent and the same number from UASB reactor effluent COD was measured. Two sludge samples were collected from the bottom of the UASB reactor to measure the total, fixed and volatile solids. The obtained results was COD removal efficiency ranged (61±8)% when the HRT was 24 hours, (50±7)% when the HRT was 12 hours and (45±4)% when the HRT was 6 hours. The sludge results was TS of 56.4 ± 8.5g/L, TVS of 38.8 ± 7.5g/L, TFS of 17.6 ± 1.0g/L, which means that the sludge contains more than 50% as bacteria. Bubbles appeared in the upper surface of wastewater within the UASB reactor during operation as an indicator of the methane gas formation. These results enabled us to rely on this system in reducing the cost of sewage treatment in Sana'a. It is recommended that UASB application is applied in the countries of the world where sewage has high strength characteristics.

KEYWORDS: UASB, anaerobic treatment, Sana'a, HRT

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INTRODUCTION

The problem in Sana'a Wastewater Treatment Plant (SWWTP) occurs due to water scarcity and a rapidly increasing population in Sana'a that led Sana'a Water and Sanitation Local Corporation (SWSLC) to use the intermittent supply which resulted in low water consumption and the production of strong wastewater. The wastewater that reaches to SWWTP contains a high concentration of BOD. BOD increased from 500mg/l in 1983 (design BOD of SWWTP) to 1100 mg/l in 2000, the quantity of wastewater that reaches to SWWTP is close to 50,000 m3/day. The remarkable increase in biological load led the top management of SWSLC to start thinking about establishing settlement ponds for the primary treatment and reducing the organic load, consequently reducing the cost of aerobic treatment stage.

Anaerobic treatment technologies, especially UASB, could be one of the most efficient ways to reduce the organic load and remove the high loading of COD with low rate sludge production, in addition to producing biogas which could be a sustainable source of energy.

The most important advantages of using a UASB reactor is the small area required for establishment in comparison with settlement ponds, which prevents the government from spending a huge amount of money as compensation to land owners. Furthermore, wastewater treatment by using UASB does not require electrical generators or complicated maintenance by a highly skilled technician (Chernicharo, 2007). The anaerobic wastewater treatment systems developed to reach the UASB reactor where the wastewater will be treated by anaerobic bacteria which digests the organic substances and covert it to gases CH4 and CO2. The UASB reactor system invented in 1970 by Gatze Lettinga showed high efficiency in reducing the concentration of organic load and decreasing the COD and BOD figures, so it spreads all over the world. Constructing a UASB reactor could be the ideal solution for reducing the high concentration of organic loading or industrial waste from milk factories and leather dying places. UASB could treat strong waste where COD exceeds 1500mg/l with COD removal efficiency reaching 90%. The main advantages of UASB systems are that it is economical in construction, operation and maintenance with no need for mechanization or energy, rather energy is produced from the methane gas. UASB provides a good contact between the wastewater which should be treated and activated sludge which is rich with anaerobic bacteria, passing the wastewater from the bottom to the top of the reactor and gas formation provides homogeneous in distributing sludge and enabling the anaerobic bacteria to consume organic substances.

LITERATURE REVIEW

UASB could be the ideal solution for reducing the high concentration of organic loading and an efficient way to remove contaminants. Constructing a UASB will save high operational costs. The result is saving money on buying land around SWWTP due to needing less land for UASB establishment compared with stabilization ponds [8]. There are similar experiences of using UASB reactors and digesters for enhancing the effluent of wastewater and gas utilization.

SUMARE EXPERIENCE IN BRAZIL

Sumare is a city 150 km from the center of Sao Paulo state. The population of Sumare is around 156,000. Sumare does not have sewage treatment that impacts the water resources and public health conditions harmfully. In order to minimize the deterioration of water resources and because of lacking funds, the city's Water and Wastewater Department (DAE) offers a proposal to low income inhabitants (235 houses). This proposal uses an anaerobic digester to treat the sewage. DAE is the financier agent for construction and management of sewage systems, in addition to plant and the inhabitants reimbursing DAE. The reactor was constructed from concrete with a fiberglass cover, the reactor design based on a UASB model of Reactor which was improved by Lettinga (the Dutch scientist), with a total cost of $29,200. The reactor started in May

1992. The volume of Sumare reactor is 67.5 m3, the HRT of UASB reactor is 7 hours, and temperature fluctuation varies from 16 degrees Celsius in winter and 23 degrees Celsius in summer. The influent and effluent Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) values were measured for 440 days. The average removal rates of BOD, COD and TSS are also higher; respectively 80%, 74% and 87%. (Vi e r i a et al., 1994)

UASB for Small Population Clusters Iran

Azimi and Zaman Zadehare two Iranian researchers at the environmental engineering faculty of Teheran University. The two researchers designed and implemented UASB reactor which was used as wastewater treatment plant for small population clusters, the volume of that reactor was 0.848m3 with average HRT 2,4,6,8 and 10 hours, the inlet was cleaned and sand removed daily, the research was conducted for 203 days during the winter and summer seasons with the temperature fluctuation from 22 degrees Celsius in winter and 26 degrees Celsius in summer. The inlet and outlet COD values were recorded to know the treatment efficiency. Figure (1) & (2) show the COD values during winter and summer [2].

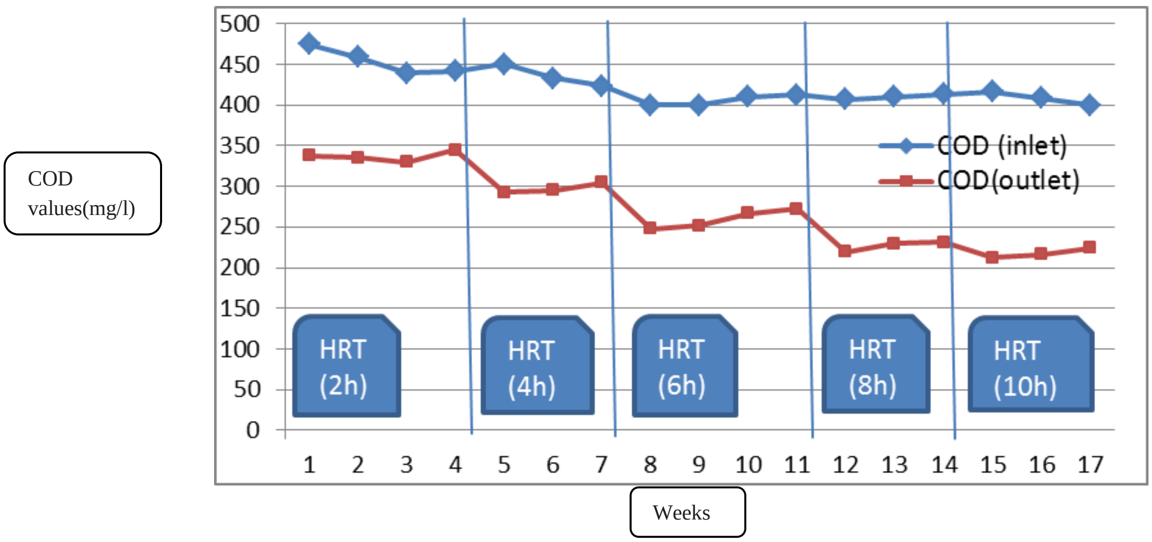

Figure 1: Results of inlet and outlet COD values during 17 weeks of winter season

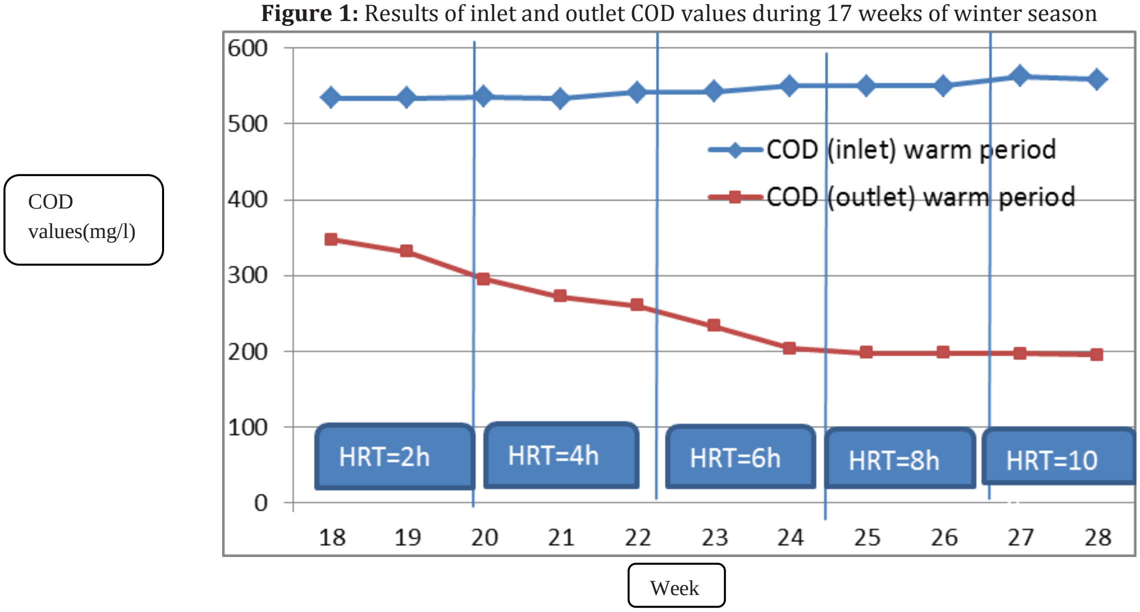

Figure 2: Results of inlet and outlet COD values during 11 weeks of summer season

INDIA

A study was conducted by Contamination Test and Energy Technology Center (CTEC) at BundiCheeri University in India. The study aimed to examine the efficiency of industrial wastewater treatment from a milk producing factory. The research studied the possibility of producing energy from organic disposed waste; 2-5 liters of water are required in producing each liter of milk.

Two reactors of UASB were constructed in 2005 to study the industrial wastewater from milk producing factory, the volume of the reactor was 1 liter and light contaminated sludge (COD<300mg/l) was used, 24 hours is considered as HRT from the reactor starting up, after the reactor reached stability in one month, different HRTs were applied and the COD of inlet and outlet results were recorded to know the efficiency of the reactor. Figure (3) shows the obtained results. (Sankar et al., 2007)

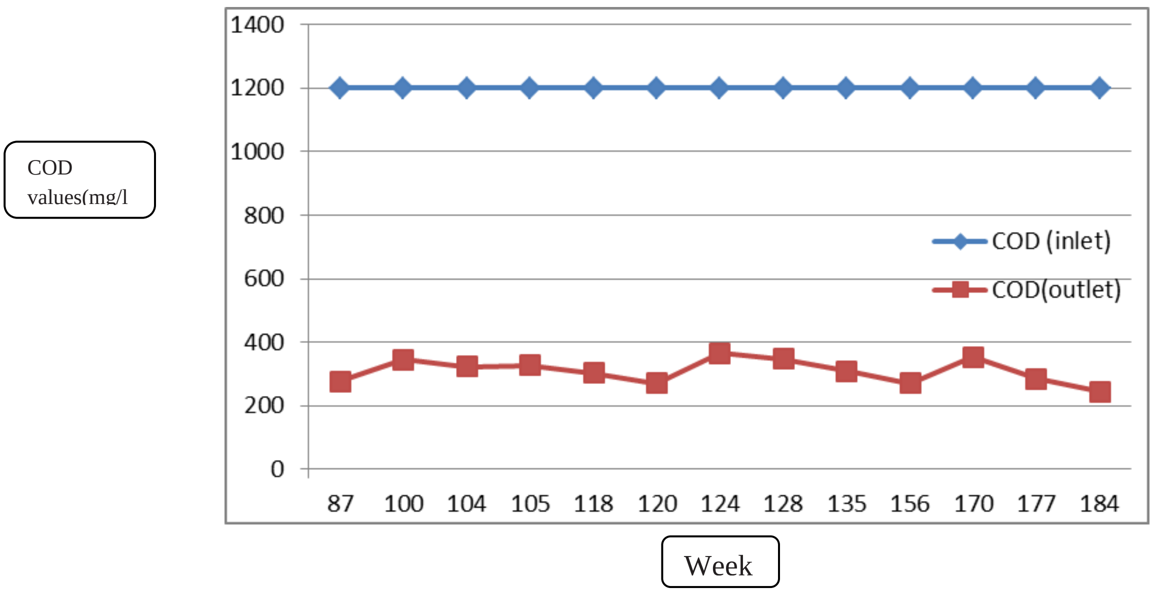

Figure 3: Results of inlet and outlet COD values during the reactor of India

JORDAN AND PALESTINE EXPERIENCE

In Jordan the results of anaerobic sewage treatment in a 64m^3 one-stage UASB reactor operated in Jordan revealed that it is quite possible to operate the reactor under the conditions of Jordan and Palestine. In this case the reactor should be operated at a prolonged hydraulic retention time of more than 22 h [7; 6].

In this experiment, a pilot-scale one-stage UASB reactor and a UASB-digester system was constructed at Al-Bireh wastewater treatment plant in Palestine. The one-stage UASB reactor was started and operated for a period of more than a year at an HRT of 10 h. The reactor volume is 140L, height 325cm and diameter 23.5cm.

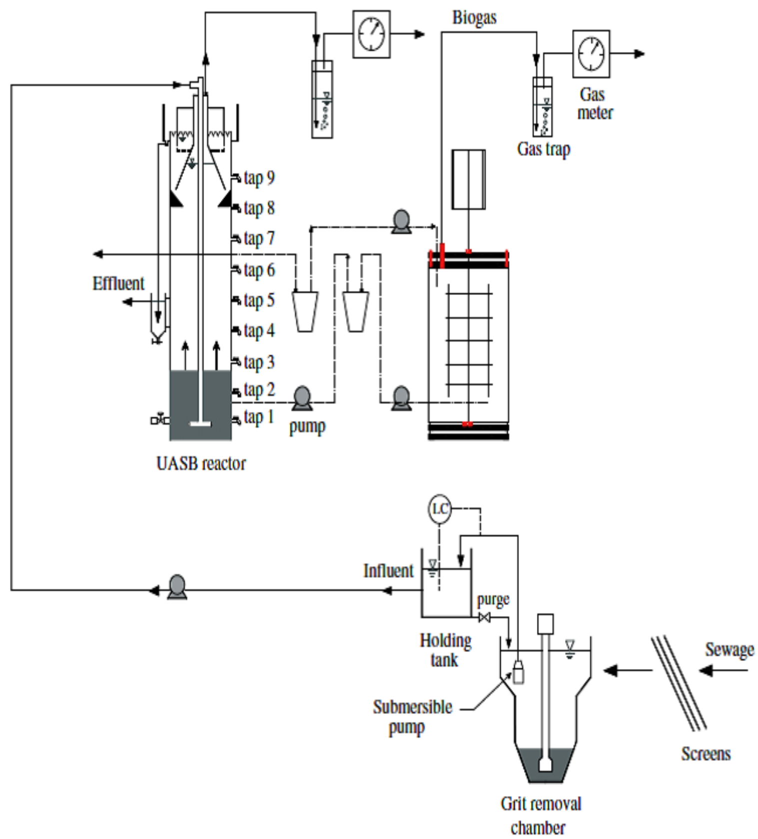

Figure 4: Schematic diagram of the UASB-digester system pilot plant

The digester fed with domestic sewage pre-treated (activated sludge after being diluted to 20 gTS/L with VS/TS ratio of 0.74 so as to achieve a SRT of 20 days) with screens and grit removal chamber content.

The sewage was pumped every 5 minutes to a plastic holding tank (200 L), with a resident time of about 5 minutes, where the reactor was fed and the influent was sampled (Figure 4). Daily monitoring and analysis for influent and effluent samples to measure and grab influent and effluent wastewater sample analysis for total COD. The influent and effluent were analyzed for total
COD fractions during summer and winter periods of the year, in addition to analyzing for BOD, TSS, NH4 and PO3. The one-stage UASB was operated for 389 days of which the first 42 days were considered as a ‘‘start-up” period.

The discharged sludge was collected in a bucket, from where the sludge was immediately fed to the digester by a peristaltic pump. At the same time, the digester effluent was pumped out to another bucket, while a third pump was recirculating it to the lower part of the UASB reactor at 10cm from the bottom. Sludge was never wasted during the system operation. The digester continuously mixed at around 60rpm.

The UASB-digester system was operated for 107 days of which the first 57 days were considered as a ‘‘start-up” period. The influent and effluent of the UASB-digester system was monitored for biogas production, temperature and COD measurements.

Total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), volatile solids (VS), ammonium (NH4), chemical oxygen demand (COD), biological oxygen demand (BOD), and PO4, were measured according to standard methods (APHA, 1995). Raw samples were used for measuring total COD (COD tot).
Nature of Jordan and Palestine experiences and are the most similar to the nature of Sana’a and Yemeni cities because of similarity of sewage influent.

Tables 1 and 2 show the results achieved from Palestine experiment.

Table 1. Influent and effluent CODtot and fractions and removal efficiencies (%) during anaerobic sewage treatment in a one-stage UASB reactor operated during the cold and warm parts of the year

	Parameter	UASB reactor						UASB-digester		
		Hot period			Cold period					
		April 05–Oct. 05			Oct. 05–April 06			July–Aug. 06		
		From day 42 to 196			From day 196–377			From day 446–496		
		#	Average	Range	#	Average	Range	#	Average	Range
Influent	COD_{tot}	24	1394(132)	1159–1701	28	1137(188)	770–1525	6	1186(272)	844–1534
	COD_{ss}	22	826(167)	548–1176	4	1024(160)	875–1244	6	767(177)	592–1089
	COD_{col}	22	196(61)	110–380	4	128(135)	35–321	6	111(83)	44–268
	COD_{dis}	22	376(69)	226–471	4	182(20)	162–209	6	308(90)	181–395
	VFA	19	123(42)	34–193				6	110(27)	79–157
Effluent	COD_{tot}	20	620(95)	443–782	26	780(144)	569–1091	6	318(24)	285–345
	COD_{ss}	20	215(69)	110–380				6	191(21)	163–221
	COD_{col}	20	120(56)	17–220				6	22(13)	6.75–42
	COD_{dis}	20	285(87)	133–518				6	105(19)	77–128
	VFA	18	113(49)	22–196				6	33(20)	0–57
Removal (%)	COD_{tot}	20	55(7)	43–69	26	32(13.5)	5–57	6	72(5.5)	63–78
	COD_{ss}	18	73(10)	57–89				6	74(5.2)	66–80
	COD_{col}	18	40(26)	−8–89				6	74(19)	40–95
	COD_{dis}	18	21(21)	−22–59				6	62(18)	30–78
	VFA	17	−4.5(57)	−170–71				6	70(19)	48–100

Standard deviations are shown in parenthesis.

Table 2: Influent and effluent characteristics in terms of CODtot, BOD, TSS, PO4 and NH4-N during anaerobic sewage treatment in a one-stage UASB reactor and a UASB-digester system UASB-digester

Influent and effluent characteristics in terms of COD_{tot}, BOD, TSS, PO_4 and NH_4^+ during anaerobic sewage treatment in a one-stage UASB reactor and a UASB-digester system

Parameter	Unit	One-stage UASB reactor			UASB-digester system		
		From day 144–day 179[a]			From day 57–day 107[b]		
		$N = 5$			$N = 6$		
		Influent	Effluent	Removal	Influent	Effluent	Removal
COD_{tot}	mg/l	1250(56)	645(63)	48(4.56)	1186(272)	318(24)	72(6)
BOD_5	mg/l	588(72)	308(68)	47(13)			
TSS	mg/l	1571(159)	1135(135)	27.8(3)	1125(631)	69(49)	93(6)
NH_4-N	mg/l	63(16)	48.8(15)	22.1(10)	84(5)	88(6)	−5(10)
PO_4-P	mg/l	12.63(5)	12.3(4)	−2.5(10)	14(1)	13(2)	8(11)
T air	°C	23(1.8)			29(2)		

Standard deviations are shown in parenthesis.
[a] The zero day is the first day of operating the UASB reactor in April 2005.
[b] The zero day is the first day sludge from the digester fed to the UASB reactor in June 2006.

THE RESEARCH OBJECTIVE

The aim of this research is to study the efficiency of anaerobic wastewater treatment in Sana'a WWTP by using UASB Reactor Pilot Plant.

MATERIALS AND METHODS

THE DESIGN PHASE OF UASB REACTOR AND ACCESSORIES

The velocity of wastewater up flow Vup<3m/h, the velocity of outlet water Vout< 3 /h

The tank of reactor was design for HRTs (6-24) hr with 2.5m depth, anaerobic bacteria was used as activated sludge.

Eng. Atfa Allah and his supervisors selected the shape of the reactor according to Dutch scientist Lettinga. The reactor is made of galvanized iron, with the following measurements:

Diameter = 64 cm

Height = 250 cm

The volume of reactor =0.804 m3.

Figure-5 shows the main components of the reactor which was located in SWWTP.

Figure 5: The main components of the pilot reactor

THE REACTOR CONSTRUCTING PHASE

After finishing the metal part of the reactor in a workshop, the internal side of the reactor was painted with anti-corrosive material; figure-6 shows more details about the reactor and accessories. The main part of reactor is installed in a place where it could be close to the inlet of raw wastewater.

The reactor accessories which is the settling tank ($1m^3$) was to receive the raw wastewater, by using a pump (power of ½ HP) to send the raw wastewater to the elevated tank ($1m^3$). The elevated tank is placed on concrete block at a height of 3.6m above the reactor to allow influent flow by gravity.

There are three valves between the reactor and elevated tanks: the first one Valve A which is opened

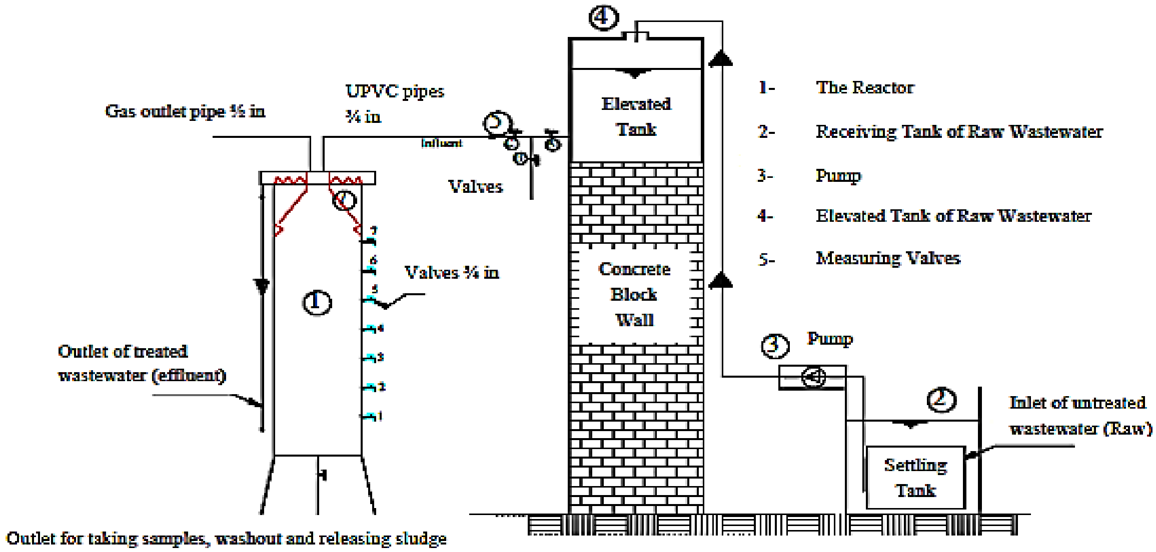

Figure 6: The main components of the pilot reactor

Partially to control the quantity, flow and retention time of the influent which feeds the reactor. Valve B which is fully opened at same time with Valve C which is fully closed during measurement to check the flow as per design. The samples were collected through Valve B.

The gas collection cone which is located upside the lower part of the cone with diameter 54cm and upper part diameter 20cm. The ½ valves (tapes) of the reactor were installed every 25 cm. The construction of the reactor

Figure 7: The components of UASB reactor and gas collection cone

took one month to finish on the site of the plant, Figure-7 shows details of gas collection cone.

THE REACTOR OPERATION PHASE

To reach a status of stable operation, the reactor requires the following:

- **SLUDGE PREPARATION :**

The sludge formed due to the sedimentation of the high concentrations of wastewater in our case the sludge was obtained by filling the reactor with the raw wastewater for one whole day, then opening all the valves mentioned above A,B and C except the valve under the reactor.

The process was repeated on the third day with all the valves opened (including taking sample valves) accept the valve number (1), in order to fill a third of the reactor with sludge, and the process was repeated again but this time the valve (3) kept open. 10 liters of rich bacterial sludge was added to the reactor to activate the formed sludge, the added sludge was collected from the digester producing biogas from cattle waste in the Veterinary Institute in Sana'a.

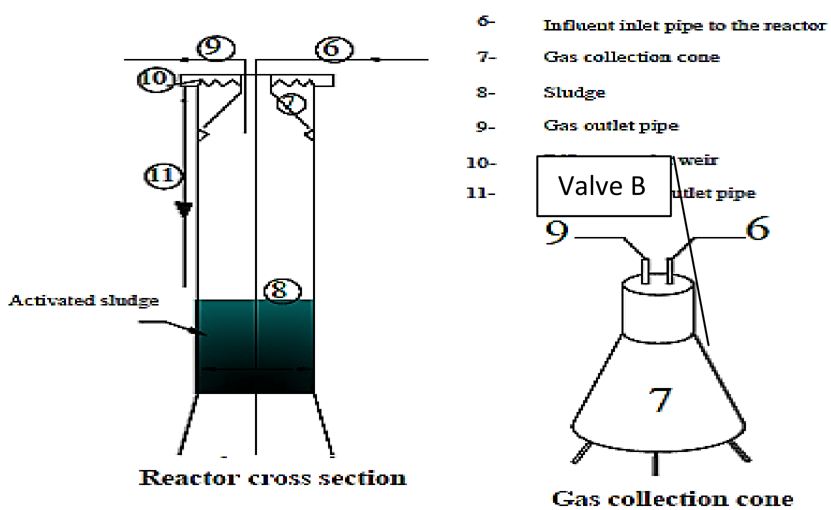

Figure 8: Adding the rich bacterial sludge to the reactor

The settling tank received raw wastewater by a suction pump from one inlet of the wastewater treatment plant. By other pump, wastewater is sent to elevated tanks through uPVC pipes which connected the two tanks. Three valves are installed to the elevated tanks to control the flow of wastewater to the reactor. The reactor was operated while one third level of the reactor with sludge, the two tanks were filled with wastewater regularly for a period of one month with a retention time of 36h, to allow the formation of anaerobic bacteria and make the reactor stable.

Then the reactor was filled with water for two weeks to dilute the concentration of organic material in wastewater. After reaching stability the reactor was operated for three different retention times 24h, 12h and 6h. Samples were taken from the inlet and outlet of the reactor in order to measure the COD values after one month.

Calculation of required flow to the reactor (Q design)
The surface area for the reactor (A) = 0.322 m^2
Volume of the reactor (V) = 0.804 m^3
The effective Volume of the reactor (Vac)= 0.563 m^3, assuming three retention times HRT1=24hr ,HRT2 =12hr ,HRT3=6hr
The flow quantity Q1=V/HRT1=23.46 l/hr, Q2= 46.92l/hr, Q3= 93.83l/hr
The flow velocity (v)
v1 =Q/A=0.073 m/hr, v2 = 0.146 m/hr, v3 = 0.292 m/hr so if v <3m/hr (Safe)

the cross sectional area of the inlet pipe (link the elevated tank and reactor)with diameter (3/4 inch)= 2.85cm2
(A2) the surface area for the pipe (between the reactor wall and the gas collection cone)
The reactor diameter = 64cm=0.64m, the gas collection cone diameter=55cm=0.55m
A2= (0.64^2-0.55^2)*3.14/4=0.094 m2
The velocity in the outlet V1-2=0.257m/hr, V2-2=0.514m/hr, V2-3=1.028m/hr< (2-3) m/hr

LAB ANALYSIS

- To measure Total Suspended Solids(TSS) by collecting sample of sludge 25ml from the lower part of reactor
- To measure Total Solids(TS) by collecting sample of sludge 50ml from the lower part of reactor
- To measure COD values Sample collection
  Different samples were taken:
- From the inlet pipe to the reactor everyday through valve B after reaching stability status
- From the outlet of the reactor everyday with respecting the different HRTs
- From the inlet of the reactor at different HRTs.(6h,12h and 24h)

RESULTS

Table 3: Results of Total Suspended Solids (TSS) from the lower part of

W1(filter paper)	W2 (filter paper and TS)	TSS (W2-W1)/25*10^6)
0.3336g	0.4618g	5128mg/l

Table 4: Results of Total Suspended Solids (TSS) from treated wastewater

W1(filter paper)	W2 (filter paper and TS)	TSS (W2-W1)/25*10^6)
0.346 g	0.35518 g	204 mg/l

Table 5: Results of Total Solids (TS) from lower part of reactor

W1(empty pot)	W2 (empty pot+ TS)	W3 (empty pot+ TFS)	TS=(W2-W1)/ 25 *10^6 Total solids	TVS=(W2-W3)/ 25 *10^6 Total Volatile Solids	TFS=(W3-W1) / 25 *10^6 Total Fixed Solids
45.6447g	46.8461g	46.0628g	47908 mg/L	31292 mg/L	16616 mg/L

TVS= $\frac{31292}{47908}$*100% = 65.3%

Table 6: Results Total Solids (TS) from rich bacterial sludge (Veterinary Institute in Sana'a)

W1(empty pot)	W2 (empty pot+ TS)	W3 (empty pot+ TFS)	TS=(W2-W1)/ 25 $*10^6$ Total solids	TVS=(W2-W3)/ 25 $*10^6$ Total Volatile Solids	TFS=(W3-W1) / 25 $*10^6$ Total Fixed Solids
0.3437g	0.9929g	0.5300	64920mg/L	46290mg/L	18630mg/L

TVS= $\frac{46290}{64290}$*100% = 71.3%

Table 7: Results of Total Solids (TS) from thickener

W1(empty pot)	W2 (empty pot+ TS)	W3 (empty pot+ TFS)	TS=(W2-W1)/ 25 $*10^6$ Total solids	TVS=(W2-W3)/ 25 $*10^6$ Total Volatile Solids	TFS=(W3-W1) / 25 $*10^6$ Total Fixed Solids
0.3454g	0.7674g	0.3955	42200mg/L	37190mg/L	5010mg/L

TVS= $\frac{37190}{42200}$*100% = 88.1%

COD values

Table 8: COD for raw and treated wastewater at retention time of 24h

No	HRT	Inlet COD)	Outlet (COD)	Treatment Efficiency
1	24	720	340	52.78%
2	24	840	260	69.05%
3	24	680	224	67.06%
4	24	1236	628	49.19%
5	24	984	404	58.94%
6	24	720	395	45.14%
7	24	850	280	67.06%
8	24	750	315	58.00%
9	24	950	325	65.79%

Table 9: COD for raw and treated wastewater at retention

No.	HRT	Inlet COD)	Outlet (COD)	Treatment Efficiency
1	12	800	380	52.50%
2	12	856	440	48.60%
3	12	884	388	56.11%
4	12	920	528	42.61%
5	12	880	500	43.18%
6	12	950	620	34.74%
7	12	840	368	56.19%
8	12	990	420	57.58%

Table 10: COD for raw and treated wastewater at retention

No.	HRT(hr)	Inlet COD)	Outlet (COD)	Treatment Efficiency
1	6	835	425	49.10%
2	6	960	520	45.83%
3	6	750	436	41.87%
4	6	700	456	34.86%
5	6	840	440	47.62%
6	6	835	425	49.10%

DISCUSSION AND CONCLUSION

Observing bubbles indicates Biogas formation due to the biological reactions inside the reactor, but non-availability of gas gauges make the measuring of biogas quantity difficult. By reviewing the results in table (10), we can conclude that the efficiency of UASB reactor ranks from 34% to 67%, this efficiency ratio which indicate that UASB reactor could be considered as efficient way to treat wastewater. Using UASB reactor to treat the high strength waste water is widely spread around the world especially for wastewater in small residential clusters and industrial wastewater without needing any external energy source. Due to the close nature of reactor (size of reactor, temperature and retention time) which was used in Sana'a UASB with the other used in Iran case study, then comparing the obtained results in two cases:

Table 11: Comparing between the results obtained from our research and Iran case study

Comparing	**The results of this research**	**The results of Iran experiment**
UASB size (M3)	0.804	0.848
HRT (Hour)	6,12,24	2,4,6,8,10
Temperature (cellos)	21average	Summer26, Winter 22
The averageCOD values inlet HRT 6 Hours	820	406
The averageCOD values outlet HRT 6 Hours	420	260
The average efficiency of UASB	45%	36%

İf the obtained results in Sana'a case study compare with India experiments in table 12. We found the following:

Table 12: Comparing between the results obtained from our research and India case study

Comparing	**The results of this research**	**The results of India experiment**
UASB size (M3)	0.804	0.001
HRT (Hour)	6,12,24	24
Temperature (cellos)	21 average	---
The average COD values inlet HRT 24 Hours	820	1200
The average COD values outlet HRT 24 Hours	352	310
The average efficiency of UASB	61%	74%

From table (12)it is remarkable that the efficiency of UASB reactor in our case study is greater than reactor in Iran case study, we could conclude that the efficiency of the reactor increased in high values of COD of inflow wastewater, and from the table above it is clear that the efficiency of UASB in India(where COD is 1200 mg/l) is greater than our research efficiency(COD value is 820mg/l) with same retention time. In Brazil other results were obtained, the table (13) below shows the comparison of Brazil reactor with our study findings:

Table 13: Comparing between the results obtained from our research and Brazil case

Comparing	The results of this research	The results of India experiment
UASB size (M3)	0.804	67.5
HRT (Hour)	6,12,24	7
Temperature (cellos)	21average	16 winter 23summer
The average COD values inlet HRT 24 Hours	820	793
The average COD values outlet HRT 24 Hours	352	311
The average efficiency of UASB	61%	56%

From table (13) above it is noticeable that the results obtained in our study are promising compared with the same results from Brazil case study.

RECOMMENDATIONS

1- It is important to continue taking the samples for the influent and effluent to reach more accurate results and know more about the advantages of UASB and minimize the disadvantages of the system.

2- It is recommended to apply UASB system for wastewater treatment in weather areas with high atmospheric temperatures where this factor accelerates the time of the anaerobic treatment process; in addition to increasing the efficiency of UASB reactor treatment.

3- The importance of constructing a second UASB reactor to compare the results of the new and old reactors.

4- It is necessary to modify the operation of the reactor to be close model of a real one:

   - Replace the two tanks with a small pump that is used in wastewater in order to avoid pipe blockages - Avoid the direct pumping from the inlet to the reactor and construct a chamber for sand removal.

5- Doing more research in this field from related water entities to find more low-cost efficient ways to treat the wastewater.

6- Involving and encouraging the private sector to use the UASB systems to treat the industrial wastewater.

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