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Sewage characterisation as a tool for the application of anaerobic treatment in Palestine

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"Capsule": *Sewage characteristics can be used to select or modify treatment processes.*

Abstract

Adequate knowledge on sewage characteristics is a prerequisite for selection and sizing of anaerobic treatment technologies, i.e. Upflow Anaerobic Sludge Blanket (UASB) systems. Composite sewage samples were collected from three locations in Ramallah/Al-Bireh district and analysed for several chemical and physical parameters, including samples fractionation into soluble, colloidal and suspended. The results revealed that the sewage in the study area is of very high strength. This is attributed to low water consumption, industrial discharges and people's habits resulting in a high specific COD production [gCOD per capita per day (gCOD/c.d)]. Simple model calculations revealed that the process conditions in a one stage UASB reactor should be modified to overcome the sewage high solids content and low temperature during wintertime.

Keywords: Anaerobic; Palestine; Sewage characteristics; UASB; Wastewater management

1. Introduction

(Waste)water management in Palestine had been neglected for decades (Daibes, 2000). Domestic and industrial wastewater used to be collected mainly in cesspools or, to a much lesser extent, in sewerage networks. In many of the Palestinian villages and refugee camps, black wastewater is collected in cesspools, while grey wastewater is discharged via open channels. The majority of the collected wastewater from the sewered localities is discharged into nearby valleys without being subjected to any kind of treatment. It is estimated that about 30% of the West Bank population is served with sewerage networks, but less than 6% is connected to treatment plants.

As the Palestinian society is facing heavy economical burdens, the application of conventional aerobic wastewater treatment technologies is too expensive and not providing a sustainable solution for environmental protection and resource conservation. Anaerobic digestion has been widely recognized as the core of sustainable waste management (Hammes et al., 2000; Zeeman and Lettinga, 1999), which has also been recognised by the Palestinian officials (PWA, 1998). The feasibility of the upflow anaerobic sludge blanket (UASB) reactor for sewage treatment has been successfully demonstrated in many tropical countries. Experience with the application of the UASB in the Middle East countries however is still limited (Zeeman and Lettinga, 1999). The main factors dictating the applicability of anaerobic technologies for domestic wastewater treatment are the sewage temperature and the characteristics and concentration of the pollutants in this sewage (Lettinga et al., 1993). Also, knowledge about the wastewater characteristics is necessary for the design and operation of treatment facilities (Metcalf and Eddy, 1991) and to determine the

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sequence of treatment systems (Levine et al., 1991). The treatability of wastewater depends strongly on the size distribution of the pollutants, since most treatment processes—physical, chemical or biological—for treatment of wastewater contaminants depend on particle size distribution (Levine et al., 1985; Ødegaard, 1999). Meanwhile, the characteristics of sewage in the West Bank, Palestine have not been subjected to good analysis [Applied Research Institute—Jerusalem (ARIJ), 1997].

This research aims at increasing the knowledge on sewage characteristics and the conceptual assessment of the technical applicability of the UASB reactor as a core technology for sustainable sewage treatment in the Middle East region, i.e. Palestine.

2. Materials and methods

2.1. Study area

Three locations were chosen for this study, all situated in the "Ramallah/Al-Bireh" district area, which is located in the central part of the West Bank and considered as one of the most important administrative centres in Palestine. Ramallah and Al-Bireh are the main urban centres for commerce and services with small and medium scale industries. According to the last census carried out by the Palestinian Central Bureau of Statistics (PCBS, 1997), the population of Ramallah and Al-Bireh are 18,017 and 27,972 inhabitants, respectively. The third location that was selected is Al-Jalazoon refugee camp, which lies about 6 k north from the centre of Ramallah and Al-Bireh, and has a population of 6144 inhabitants (PCBS, 1997).

According to the records of JWU (2000; the water supplying company), the average billed water consumption per capita is 103 l/d for the total area. The consumption for the two cities Ramallah and Al-Bireh is higher amounting to 137 l/c.d, while for Al-Jalazoon, this is only 51 l/c.d.

Sewage from Ramallah and Al-Bireh is collected in sewer systems, serving about 75% of the population. The remainder is collected in septic tanks or cesspools. The treatment plant in Ramallah, which consists of aerated lagoons followed by stabilisation ponds, is overloaded and poorly maintained. The recently built treatment plant of Al-Bireh is an oxidation ditch. In Al-Jalazoon, sewage is mainly collected in open channels running along the sides of the camp's streets and discharged to down stream wades without any kind of treatment.

3. Sampling

Samples were collected from the sewerage outfall of the three study locations: Al- Bireh City, Ramallah City and Al- Jalazoon refugee camp. Time–interval composite samples were collected every 2 h from 10:00 to 16:00 on Saturday, Tuesday and Thursday for 3 weeks in September 2000. Samples of 4 l were collected from the mentioned locations; 1-l grab sample was gathered from each location for each cycle and combined in 4-l plastic containers. All samples were preserved during the sampling time by storing them in special insulated boxes at 4 °C.

3.1. Analysis

Total suspended solids (TSS), volatile suspended solids (VSS), ammonium (NH_4^+–N), kjeldahl-nitrogen Nkj, total PO_4–P, dissolved PO_4^{3-}–P and SO_4^{2-}–S were all determined according to standard methods (APHA, 1995). Raw samples were used for measuring total COD (CODt), 4.4 μm folded paper-filtered (Schleicher and Schuell 5951/2, Germany) samples for paper filtered COD (CODp) and 0.45 μm membrane-filtered (Schleicher and Schuell ME 25, Germany) samples for dissolved COD (CODdis). The suspended COD (CODss) and colloidal COD (CODcol) were calculated as the difference between CODt and CODp and the difference between CODp and CODdis, respectively. Carbohydrates in raw, paper-filtered and membrane-filtered samples were determined photometrically according to the method described by Bardley et al. (1971) with glucose as standard. VFA were determined in membrane-filtered samples by gas chromatography. The chromatograph (Hewlett Packard 5890A, Palo Alto, USA) was equipped with a 2 m × 2 mm (inner diameter) glass column, packed with Supelco port (100–120 mesh) coated with 10% Fluorad FC 431. Operating conditions were: column, 130 °C; injection port, 200 °C; flame ionisation detector, 280 °C. N_2 saturated with formic acid at 20 °C was used as a carrier gas (30 ml/min). Settleable solids were measured after settling for 30 min in an Imhoff cone (Metcalf and Eddy, 1991). Biodegradability of raw samples was measured in 500 ml working volume batch reactors incubated at 30 °C for a period of 60 days. Each batch was filled with 450-ml wastewater, and mineral solution contains macro and mico nutrients and a buffer. The mineral composition inside the batch reactors was: *Macro nutrients* (g/1*)*: NH_4Cl, (0.28); $MgSO_4.7H_2O$, (0.1); K_2HPO_4 (0.25); $CaCl_2.2H_2O$, (0.01); yeast extract (0.05); $NaHCO_3$ (2.5); *1 ml/l trace elements containing (g/1)*: $FeCl_2.4H_2O$ (2), H_3BO_3 (0.05), $ZnCl_2$ (0.05), $CuCl_2.2H_2O$ (0.038), $MnCl_2.4H_2O$ (0.5), $(NH_4)_6Mo7O_{24}.4H_2O$ (0.05), $AlCl_3.6H_2O$ (0.09) $CoCl_2.6H_2O$ (2), $NiCl_2.6H_2O$ (0.092), $Na_2SeO_3.5H_2O$ (0.164); resazurin (0.2); EDTA $C_{10}H_{16}N_2O_8$ (1); 36% HCL (1.0 ml/l). COD total was measured at the beginning and the end of the batch period. All samples were analysed in duplicate.

Sewage temperature was measured in situ for each grab sample by an alcohol thermometer. The ambient temperature was measured with an alcohol thermometer placed at the Al-Bireh sewage treatment plant. Sewage temperatures during the other sampling period have been measured four times during January, February and March—winter 2000. Colour was determined by visual appearance.

3.2. Calculations

- 1 g protein, assumed as $(C_4H_{6.1}O_{1.2}N)x$ is equivalent to 0.16 g Nkj–N, 0.16g NH_4–N and 1.5 g COD (Sanders, 2001)
- 1 g carbohydrates (assumed as $C_6H_{12}O_6$) is equivalent to 1.07 g COD (Sanders, 2001)
- Biodegradability (BD) = $100\times(COD_{t,\ t=0\ day} - COD_{t,\ t=60\ day}) / COD_{t,\ t=0\ day}$

4. Results and discussion

4.1. Sewage characteristics

4.1.1. General observations

The results presented in Table 1 elucidate two main observations on sewage characteristics of the study locations. Firstly, the sewage of the three locations are classified of high strength, since, the mean values of COD, Nkj, phosphorus, sulphate, ammonia, TSS and VSS are very high according to the sewage strength classification proposed by Metcalf and Eddy (1991) and Henze (1997) and as compared with sewage characteristics in several countries in Europe, Asia and Latin America (Table 2). Secondly, the sewage characteristics of Al-Bireh City and Al-Jalazoon refugee camp are very similar and of domestic type, while they differ from those of Ramallah City which has much higher pollutant concentrations. The Ramallah sewage characteristics are highly influenced by industrial discharges which can clearly be observed in the measured parameters (COD, carbohydrate, TSS, VSS, protein, sulphate concentrations and high wastewater temperature), and also from visual observation of the colour variation of each collected grab sample during the same sampling day due to discharges of dying factories, food and beverage industries.

4.1.2. Anaerobic biodegradability

The anaerobic biodegradability of the sewage of the three locations measured after 60 days are presented in Table 1. Unfortunately, the test period was far too short for achieving a stabilisation of organic matter. Elmitwalli et al. (2001) found that the sewage biodegradability of Bennekom village in The Netherlands was 21% after 43 days and increased to 74% after 135 days at 30 °C. Likewise, Kerstens (2001) found high biodegradability of 76% (after 130 days' incubation at 33 °C) of the sewage of Amman City, Jordan which is, from a socio economic point of view, very close to the Palestinian cities. The previous discussion indicates that, the biodegradability of Ramallah, Al-Bireh and Al-Jalazoon wastewater is much higher.

4.1.3. Size fractionation of COD

The results of COD fractions of the three locations are presented in Table 1. The results reveal that the main fraction of COD is particulate, as the suspended, colloidal and dissolved fractions of COD of all studied areas are in the ranges 49–58%, 15–22% and 25–35% of the total COD, respectively. In view of that, the percentage particulate COD (colloidal and suspended) of total COD for Ramallah, Al-Bireh and Al-Jalazoon is 65, 75 and 71%, respectively. Wang (1994) found that the COD fraction of the particles exceeding 0.45 μm in domestic sewage represents about 70% of the total COD. Levine et al. (1985) found also that the COD fraction of the particles larger than 0.1 μm is in the range of 30–85% of the total amount of organic materials present in the pre-settled sewage.

4.1.4. Size fractionation of carbohydrate

The results of the carbohydrate fractions for the three locations are presented in Table 1. The suspended, colloidal and dissolved carbohydrate fractions are in the range of 36–74, 9–12 and 17–52% of the total carbohydrates, respectively. The suspended carbohydrate forms the major fraction for Al-Bireh and Al-Jalazoon, while the dissolved form is the major fraction in Ramallah sewage. This can be explained by the existence of food industries in Ramallah such as Coca-Cola and chocolates, which discharge their wastewater in the municipal sewer system. Likewise, Elmitwalli (2000) showed that carbohydrate is mainly present in the suspended form in the domestic sewage of the village of Bennekom, The Netherlands.

4.1.5. Volatile fatty acids

The results of VFA and COD ratios presented in Table 3 show that around 35% of the dissolved COD are in the VFA form for Al-Bireh and Al-Jalazoon, and 27% for Ramallah. The results also show that around 25% of the total COD in Al-Bireh and Al-Jalazoon are present in hydrolysed form and a higher value of around 40% for Ramallah. The acidified fraction is around 10% for all three locations.

4.1.6. Nkj–N, NH_4^+–N and proteins

The Nkj–N values for Ramallah and Al-Bireh are nearly the same, but it is lower for Al-Jalazoon (Table 1). Comparing the values of Nkj–N and NH_4^+–N showed that the NH_4^+-N is the major fraction of Nkj–N. In addition, the results presented in Table 4 reveal that the highest protein content exists in Ramallah

Table 1
Sewage characteristics of Ramallah City, Al-Bireh City and Al-Jalazoon refugee camp[a]

Parameters	Samples	Ramallah		Al-Bireh		Al-Jalazoon	
		Range	Average	Range	Average	Range	Average
COD Total	8	1518–3812	2180 (663)	1411–1844	1586 (125)	1092–1773	1489 (251)
Suspended	8	545 – 1925	1096 (456)	720–1209	919 (157)	518–990	725 (153)
Colloidal	8	107– 525	323 (101)	171–362	274 (52.4)	213–440	327 (71.3)
Dissolved	8	468–1482	761 (297)	280–464	393 (62.3)	258–613	438 (113)
Carboh. Total	5	100–231	178.4 (52.6)	99–166	131 (22.8)	59–155	93.5 (32.7)
Suspended	5	45–90	64.1 (20.2)	67–132	97.4 (25.3)	28–88	44.8 (21.3)
Colloidal	5	10–35	21.6 (10)	9–14	11.7 (1.8)	4–14	9.9 (3.7)
Dissolved	5	37–157	92.6 (55.4)	17–37	22.2 (7.4)	15–60	38.8 (17.3)
VFA as COD	2	175–199	187 (12)	155–162	160 (3.1)	100–145	123 (25.4)
Nkj as N	6	54–119	99.4 (23.2)	85–122	104 (14.7)	53–83	71 (10)
NH_4^+ as N	8	47–72	58 (8.5)	72–89	80.1 (5)	40–77	56.2 (9.5)
Proteins[b]			388		224		139
Total PO_4 as P	3	10–15	12.8 (2.2)	11–14	13 (1.5)	11–18	15 (2.4)
PO_4^{3-} as P	5	6–17	12.4 (3.8)	8–15	12.9 (2.6)	8–14	11.9 (2.4)
SO_4^{2-} as SO_4^{2-}	4	474–2060	975 (742)	129–151	138 (9.9)	143–277	213 (57)
TSS	5	510–1096	729 (197)	610–824	736 (67)	408–1048	630 (234)
VSS	5	255–892	584 (209)	492–676	617 (66.1)	364–733	480 (148)
Settleable solids	7	4–105	43.5 (41.1)	8.5–13.5	10.9 (2.2)	1.2–8	2.9 (2.4)
pH	4	7.18–8.02	7.45 (0.39)	7.16–7.44	7.26 (0.13)	7.11–7.58	7.31 (0.2)
T_{ww} Summer	8	26–40	30.9 (3.19)	24–27	25.8 (0.67)	20–25	23.4 (1.52)
Winter	4			12–13	13.13 (0.63)		
T_{amb}. Summer	8			21–33	27.1 (3.17)		
Winter	4			11–17	13.8 (2.75)		
Biodegradability (%)	2	46–49	47 (1.4)	34–40	36 (3.2)	32–35	33 (1.5)
Colour	8	Reddish to black		Medium brown		Light brown	

[a] Standard deviations are presented between brackets. All parameters have been measured in duplicate and their units are in mg/l except settleable solid in ml/l; wastewater temperatures (T_{ww}) and ambient temperature (T_{amb}) (°C); pH no unit; Biodegradability (%); Proteins mg COD/l.
[b] Calculated.

Table 2
Sewage characteristics of different cities in different countries and continents[a]

Parameter	Palestine Al-Bireh[b]	Jordan, Amman[c]	Egypt rural areas[d]	Turkey, Istanbul[e]	The Netherlands, Bennekom[f]	Brazil, Campina Grande Pedregal[g]	Columbia, Cali[g]
CODt	1586	1183	824.9	410	528	727	267
CODss	919	608	–	–	225	–	–
CODcol	274	174	–	–	156	–	–
CODdis	393	401	270.2	140	147	–	112
VFA–COD	160	104–177	–	–	55	–	–
NH_4^+–N	80	80	26	30	48	34	17
Nkj–N	104	109	33.8	43	70	44	24
Total P	13	–	8.9	7.2	18	11	1.3
PO_4^{3-}–P	12.9	–	3.87	4.5	14	8	–
Lipids-COD	–	443	302	–	–	–	–
Protein-COD	224	272	–	–	–	–	–
TSS	736	420	310	210	–	492	215
VSS	617	330	277	145	–	252	108
VSS/TSS	84	79	89	70	–	51	50
Temperature		16–24	–	–	8–20	24–26	24.4–25

[a] All parameters are in mg/l except: temperatures (°C); VSS/TSS ratio.
[b] This study.
[c] Kerstens (2001).
[d] Tawfik (1988).
[e] Orhon et al., 1997.
[f] Elmitwalli, 2000.
[g] Haandel and Lettinga (1993).

Table 3
Percentages of hydrolysis and acidification of total COD and acidification of dissolved COD and VSS/TSS and CODss/VSS ratios for the sewage of Ramallah and Al-Bireh cities and AL-Jalazoon refugee camp-Palestine

	Parameter	Ramallah	Al Bireh	AL-Jalazoon
Acidified fraction	VFA/CODt	10	10	9
Acidified of dissolved	VFA/CODdis	27	36	35
Hydrolysed fraction	CODdis/CODt	39	28	25
	VSS/TSS	80	84	76
	CODss/VSS	1.88	1.49	1.51

Table 4
Percentages of carbohydrates, proteins and VFA out of total COD for domestic/municipal wastewater of Ramallah, Al-Bireh cities and AL-Jalazoon refugee camp-Palestine and Bennekom village, The Netherlands

Parameter	Ramallah	Al-Bireh	AL-Jalazoon	Bennekom, The Netherlands[a]
Carb-COD/CODt	8.8	8.9	6.7	12
Protein-COD/CODt	18	14	9	44
VFA/CODt	10	10	9	9
Sub total COD	36.8	32.9	24.7	65

[a] Elmitwalli (2000).

wastewater followed by Al Bireh and the lowest concentration is found in Al-Jalazoon wastewater. This might be justified by the presence of the main district (chicken) slaughterhouses in Ramallah City.

4.1.7. Total phosphorus and ortho-phosphate

The measured values of both total phosphorus and ortho-phosphate are presented in Table 1. The results show that the values of total phosphorus are approximately equal to the values of ortho-phosphate for the three locations, which is in conformity with Butler et al. (1995).

4.1.8. Sulphate

The sulphate concentration in the sewage of the three studied locations (Table 1) is very high according to the classification proposed by Metcalf and Eddy (1991). This especially applies for Ramallah where the sulphate concentration range is 474–2060 mg/l. The reason for that is the presence of several industries consuming large quantities of sulphur and sulphuric acid, especially a number of dyeing factories. The water consumption records of the JWU reveal that the water consumption of the dying factories in Ramallah City during the year 2000 was 108,000 m^3, which represented around 10% of the total water consumption of the city. The major problem associated with the anaerobic treatment of sulphate-rich wastewater is the production of sulphide. Since sulphide can lead to several problems such as toxicity, bad smell, corrosion, deteriorated quantity and quality of the biogas and reduction of the COD removal efficiency. In practice, anaerobic treatment always proceeds successfully for wastewater's with chemical oxygen demand (COD) to sulphate ratios exceeding 10. At COD/sulphate ratios lower than 10, process failures of anaerobic reactors have been reported (Hulshoff Pol et al., 1998). Accordingly, the high sulphate content of Ramallah sewage might suppress its anaerobic treatment as the COD/sulphate ratio can be as low as 0.74. Nevertheless, calculation of the maximum possible H_2S production reveals that the H_2S will always be below the IC_{50} concentration (50% inhibition concentration) of 250 mg H_2S–S, which indicates the occurrence of only partial inhibition during anaerobic sewage treatment. Moreover, the high sulphate content is harmful to the sewerage system. As H_2S gas may be oxidised to H_2SO_4 that causes damages to cement containing constructions such as manholes and pipes (Metcalf and Eddy, 1991).

4.1.9. TSS and VSS

The TSS and VSS values of the three locations are high (Table 1). The results presented in Table 3 reveal high values of VSS/TSS for the three locations. Apparently, the data presented in Table 2 indicate that the VSS/TSS ratios of sewage in Palestine, Jordan and Egypt are high in comparison with Turkey, Brazil and Columbia. This might be due to difference in people's habits. The high CODss/VSS of Ramallah wastewater indicates high lipids content, possibly due to discharge of slaughterhouses wastewaters.

4.1.10. COD mass balance

The results presented in Table 4 indicate that a high fraction of biodegradable COD should be lipids (25–50% of total COD is estimated to be lipids) as proteins, carbohydrates and lipids are the main biopolymers in sewage (Levine et al., 1991). This is obvious from the low values of COD subtotal and the large difference when we compare the subtotal COD in the studied areas with the sewage of Bennekom, The Netherlands. However, the sulphide COD was not accounted for.

4.1.11. Grey wastewater

Regarding Al-Jalazoon refugee camp, it was believed that only grey wastewater is disposed in the open channels (Amarneh, 2001). This study shows that Al-Jalazoon wastewater is of high strength and is similar to Al-Bireh wastewater COD. The high content of NH_4^+–N and Nkj in the sewage of Al-Jalazoon indicates the discharge of black wastewater with the grey water. The sulphate is originating from the drinking water (~55 mg SO_4^{2-}/l), proteins and the detergents, which contains sulphate rich compounds like sodium lauryl sulphate, ammonium sulphate, etc.

4.1.12. Specific waste production

The calculated specific waste production for Ramallah and Al-Bireh cities in terms of COD, N and P are presented in Table 5. In order to obtain a reference waste, the household waste production, source and composition for some countries (Germany, Denmark and Sweden) compiled from several literature sources by Henze (1997) are presented in Table 6, in addition to other data for the Dutch society (Kujawa-Roeleveld et al., 2000). The data in both tables show that the COD specific waste production in the waterborne waste of Ramallah and Al-Bireh is substantially higher than the reference wastes (Table 6). These values are as high as the total (solid and waterborne) specific waste of the reference countries and in Ramallah it can even be two times higher. This suggests that the high COD content of sewage in Palestine and other countries in the Middle East, like Jordan (Table 2), is not only due to low water consumption, but also due to industrial discharges (Ramallah) and/or people's habits. Discarding the remaining food and used cooking oil in kitchen sinks is believed to play a central role in increasing sewage strength in Palestine. Henze (1997) shows that the application of 'clean tech cooking' can reduce the COD load of grey water from 55 gCOD/c.d to 32 gCOD/c.d.

The data in Table 6 show that kitchen waste contributes around 35% to the COD content of the household traditional waterborne wastes, and can even be much higher in cases where more solid waste is directed to the sewer system. The COD content of wastewater can be significantly reduced by separating part of the kitchen wastes [clean tech cocking described by Henze (1997)] and toilet wastes (Zeeman and Lettinga, 2001; Henze and Ledin, 2001; Henze, 1997). Likewise, separation of the toilet wastes (physiological wastes) from the waterborne route will lead to a significant reduction in nitrogen and phosphorous. The N specific waste production of Ramallah and Al-Bireh is similar to the reference wastes. The P specific waste production is similar to Holland, but different from those reported for Denmark, Sweden and Germany. Moreover, the presented data reveal that 77–85% and 47–60% of the waste waterborne N and P content originates from urine.

Table 5
Specific production (g/c.d) and composition of waterborne household wastes in Ramallah and Al-Bireh cities, Palestine

	Ramallah	Al-Bireh
COD	166–418	155–202
N	5.9–13.0	9.3–13.4
P	0.7–1.9	0.9–1.6

Notes: calculated based on billed water consumption of 137 l/c.d of which 80% ends up in the sewer system (Nashashibi and van Duijl, 1995) and the measured parameters shown in Table 1. Pollutants due to industrial discharges are neglected

4.2. Application of the UASB reactor in Palestine

The final removal efficiency and conversion of organic compounds to methane gas in UASB systems depend on both physical and biological processes. For sewage, removal of suspended solids occurs by physical processes like settling, adsorption and entrapment. The subsequent hydrolysis and methanogensesis of the removed solids depends on the process temperature and the prevailing sludge retention time (SRT). Zeeman and Lettinga (1999) developed a model for the calculation of the HRT when a certain SRT is a pre-requisite [Eq. (1)].

$$\mathrm{HRT} = (C\,{}^{*}\mathrm{SS}/X)^{*}\mathrm{R}^{*}(1\text{-}H)^{*}\mathrm{SRT} \quad (1)$$

Where,
HRT: hydraulic retention time
C: COD concentration in the influent (g COD/l)
SS: fraction of the influent suspended solids
X: sludge concentration in the reactor (g COD/l); 1 g VSS = 1.4 g COD
R: fraction of CODss removed
H: fraction of removed solids that are hydrolysed
SRT: sludge retention time (days)

Table 6
Production and composition of total (solid and waterborne) and traditional total waterborne household wastes, g/c.d for some countries in western Europe)

Param.	Denmark, Sweden and Germany[a]						Holland[b]
	Total		Source of waste				Total
	Solids and water-borne	Water-borne	Physiological total (urine)	Kitchen, liquid	Wash and bath	Kitchen solids	Water-borne Total (physiological <urine>)
COD	220	130	75	45	10	90	102 (56)
N	13.3	13	11 (10)	1	1	0.3	12.9 (12.5 <11>)
P	4.5[c]	2.5[c]	2 (1.5)	0.2	0.3	2	1.7 (1.4 <0.8>)

[a] Henze (1997).
[b] Kujawa et al. (2000).
[c] The phosphorous load from the washing of clothes will be increased by some extra 1–1.5 g P/c.d, if phosphate rich detergents are used (Henze, 1997).

The previous model was used for the calculation of the required HRT for the application of a one-stage UASB reactor for sewage treatment in Al-Bireh City. The following input data were taken into consideration:

$R = 0.80$, Mahmoud (2002) found around 80% suspended COD removal efficiency in a UASB operated at $V_{up} = 0.50$ m/h; $R = \frac{\text{CODss influent} - \text{CODss effluent}}{\text{CODss influent}} \times 100\%$

$H = 0.15$; 15% of the TS are hydrolysed at process conditions of 15 °C and 75 days SRT [winter conditions] (Elzen and Koppes, 2000)

$X = 15$ g VSS/l = 21 g COD/l

SS = 0.58, (this study)

$C = 1.586$ g COD/l (this study)

SRT = 30 days, expected minimum SRT to achieve methanogenic conditions during winter time (Elzen and Koppes, 2000)

Accordingly, the model calculation revealed that a minimum HRT of 22 h is required for the application of a one-stage UASB reactor in Palestine to overcome the wintertime. The calculated HRT is long in comparison with HRTs generally applied in tropical countries (6–12 h). The long HRT to be applied is due to the high concentration and the relatively low temperature in winter. It is worth mentioning that we have recently researched (Mahmoud, 2002) a novel technology consisting of a high loaded UASB integrated with a digester with sludge re-circulation to solve the technical applicability of the UASB system in the Middle East during the short period of winter. Promising results have been obtained which showed that the UASB-digester system could be successfully operated at a much lower overall equivalent HRT. In this system, the influent suspended solids are partially captured in the UASB reactor and conveyed to the digester, which is operated under optimal process conditions with respect to temperature and SRT. The methanogen enriched digested sludge is recirculated to the UASB reactor to improve the methanogenic capacity of the UASB reactor, and thus methanogenize the influent VFA.

5. Conclusions and recommendations

The results of this study reveal that the sewage in Palestine is characterised by high strength and solids content. Accordingly, the application of a one-stage UASB reactor in Palestine is only possible if designed at a prolonged HRT due to low solids hydrolysis during wintertime. However, reform in the household sanitation habits will reduce the solids content, and therefore, influence the selection of the proper treatment technology. In addition, the factories should apply a pre-treatment step before discharging their wastewaters in the municipal sewerage system. This highlights the urgent need for issuing an environmental act and enforcing the implementation of environmental regulations. On the other hand, those industries that use high amounts of sulphate can recover the sulphur element, which will reduce the treatment cost via application of the concepts of cleaner production.

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