Final Report

CHARACTERIZATION OF SEPTAGE DISCHARGING TO KHIRBIT AS SAMRA TREATMENT PLANT

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EXECUTIVE SUMMARY

Septage composite samples were collected from Ain-Ghazal pre-treatment facility and analyzed during the period Feb., 2007 to the end of Oct., 2007. Septage showed different concentrations of pollutants during winter compared with summer. The average total COD was found to be 2.16 times higher during summer compared with winter time with average values of 6425 and 2969mg/l for summer and winter respectively. The $BOD_{5(tot)}$ represents 45% of the total COD during both winter and summer. However, VSS/TSS had average values of 0.57 and 0.52. It should be noted that digested sludge has usually VSS/TSS ratio ranging 0.3-0.6. A major concern when septage has to be treated separately and reused for irrigation is the high EC values averaging 6226 µs/cm and 5626 µs/cm for winter and summer, respectively. Septage discharging at Ain-Ghazal pre-treatment facility also contains high counts of Total and fecal coliforms with average values of 1.8×10^{10} MPN/ml and 2.2×10^{9} MPN/ml, respectively during winter and 1.2×10^{13} MPN/ml and 1.1×10^{13} MPN/ml, respectively during summer. These values are higher than those reported for other locations in Jordan. Nematode eggs were also present with high concentrations averaging 98 and 87 eggs/l for winter and summer, respectively. Heavy metals concentrations were found to be lower compared with values reported for the USA and EPA as shown in the report. Anaerobic biodegradability was found to be 75% after 81 days of digestion at 37°C with hydrolysis constant (k_h) value of 0.024 d^{-1}, which is low compared with 0.113 d^{-1} reported for primary sludge digested at 35°C (Mahmoud, 2002). However, the high biodegradability of the septage is comparable with anaerobic biodegradability tests measured previously for the influent to Abu Nusier wastewater treatment plant, which receives wastewater with solely domestic origin. Biodegradability of the influent to Abu Nusier wastewater treatment plant was found to be 76% of the biodegradable fraction after 130 days of digestion at 25°C (Halalsheh, 2002). Aerobic biodegradability was also measured for septage and found to be 48% after 7 days of digestion at 37°C. Biodegradation rate was measured to be 0.46 d^{-1}.

Septage discharging at Ain Ghazal pre-treatment facility contribute to 7.0-13% of the organic load (COD basis) arriving at Khirbit As-Samra wastewater treatment plant. However, the comparable biodegradability values of spetage and influent to a wastewater treatment plant that receives solely domestic sewage suggests that septage does not have a negative effect on the performance of Khirbit As-Samra wastewater treatment plant with respect to biodegradation process. Organic material present in septage can be treated to the same degree as organic material present in domestic wastewater and at a comparable rate.

INTRODUCTION

Jordan is a country with a total population of 5.5 Million inhabitants. More than 57% of the collected wastewater in the kingdom (WAJ, 2006a) is treated in Khirbit As-Samra treatment plant that serves the Capital Amman, Zarqa and Rusaifeh cities with a total population of 2.7 Million inhabitants (Department of Statistics, 2004). The plant was originally put into operation on 1985 as a temporary solution for the overloaded Ain Ghazal activated sludge treatment plant, which was treating sewage produced by the population of Amman. However, the later closure of Ain Ghazal treatment plant had directed the operation of Khirbit As-Samra plant as a permanent solution. Pre-treatment facilities at Ain Ghazal plant were kept into operation before the collected wastewater is transferred by 40 km inverted siphon to Khirbit As-Samra treatment plant in Zarqa district (Figure 1). The latter plant was used for treating additional sewage produced by Zarqa and Rusiefeh cities. The stabilization ponds treatment plant was the largest of its kind in developing countries and consists of 32 ponds occupying 200 ha (Figure 2). The plant receives currently 221,507 m^3/day of wastewater (WAJ, 2006a), while it was designed to treat 68,000 m^3/d. The heavily overloaded plant resulted in the emission of noxious odors from the anaerobic ponds; poor quality effluent, which is far beyond Jordanian reclaimed water quality effluent standards; and negative effects on the irrigation systems down stream of the treatment plant where reclaimed water is used for restricted irrigation before King Talal Reservoir and for unrestricted irrigation -after mixing with fresh water- down stream of the reservoir (Figure 1). The unacceptable poorly sustainable situation and the frequent complaints of local community led the government to seek other alternatives. A wastewater master plan financed by the USAID was prepared for the Amman-Zarqa basin for the period 2000-2025.

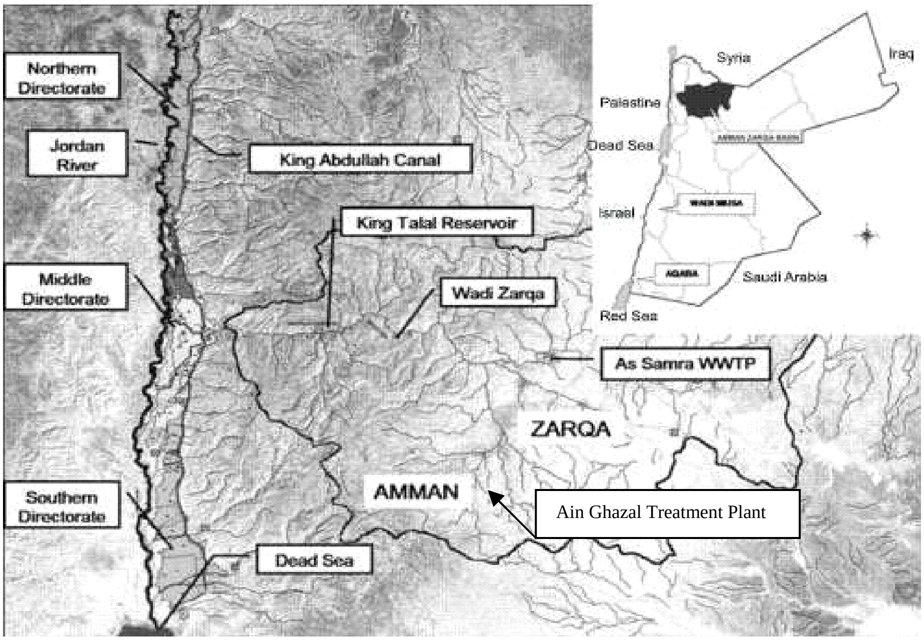

Figure 1. Location of Khirbit As-Samra Wastewater Treatment Plant.

Based on the recommendations of the master plan, the government had decided to construct a new activated sludge treatment plant at the same site of the existing overloaded plant. The Samra Plant Consortium (SPC) consisting of Suez Environment, Ondeo Degremont and Morganti Group were selected for the BOT project on the year 2000. The project includes the design, construction, procurement, commissioning, operation, maintenance and financing of the first stage of the new plant, which will be capable of treating 267,000 m^3/d of wastewater (www.mwi.gov.jo) until the year 2010. The project also includes expansion and upgrading of the pre-treatment plant at Ain-Ghazal, the minor refurbishment of the pumping station at West Zarqa, as well as the operation and maintenance of the main conveyor lines from the pre-treatment facilities at Ain Ghazal to the WWTP and of the pumping stations at Hashimmiyya and West Zarqa used to pump sewage from Zarqa city to Khirbit As-Samra treatment plant.

1. Need for Characterization: Problem definition

In addition to wastewater discharge, Khirbit As-Samra Stabilization Ponds currently receive domestic septage collected from un-sewered areas in Amman and excess sludge produced by Abu-Nusier, Baqa'a, Salt and Fuhais treatment plants. Septage and sludge discharges take place at Ain Ghazal pre-treatment facility with an average daily flow of around 7000 m^3/day (WAJ, 2006b). According to Halalsheh *et al*., (2004), these

Figure 2. Khirbit As-Samra Waste Stabilization Ponds.

discharges may contribute to the lower anaerobic biodegradation rates measured for the influent to Khirbit As-Samra plant compared with the influent to Abu Nusier treatment plant, which solely receives domestic sewage (Figure 3). It was found that both wastewaters have high anaerobic biodegradability with values of 79% and 76% -COD basis- respectively. However, the rate of biodegradation was higher for Abu-Nusier influent with 86% of the biodegradable fraction digested after 27 days of incubation at 25^{o}C compared to 57% digested for Khirbit As-Samra influent. Lower biodegradation rate of the influent to Khirbit As-Samra plant was attributed to the

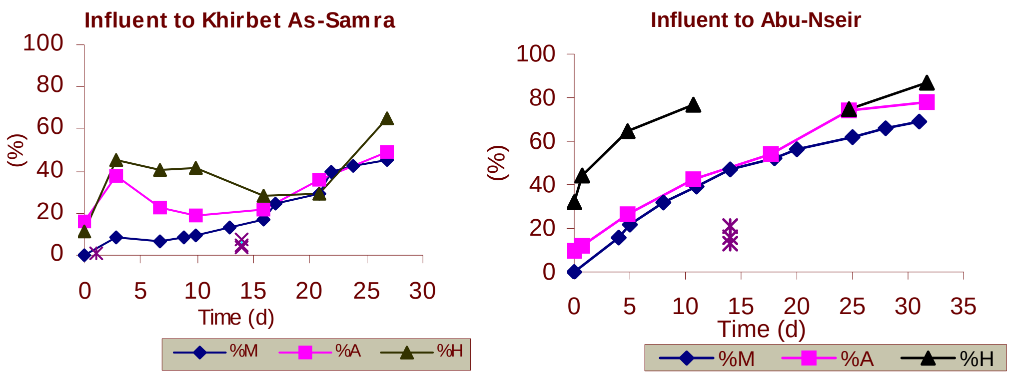

Figure 3. The calculated hydrolysis (H), acidification (A) and methanogenesis (M) for the influents to Khirbit As-samra treatment plant and Abu Nusier treatment plant at 25^{o}C

lower biodegradation rate of proteins, viz. 0.025 d^{-1} versus 0.08 d^{-1} for Abu-Nusier wastewater. It should be mentioned that other factors like illegal industrial discharges could also contribute to the lower biodegradation rate of the influent to Khirbit As-Samra plant. The Samra Plant Consortium will not allow sludge and spetage discharges into the new plant after its operation by the end of 2006 due to the expected interference with the performance of the activated sludge plant. Consequently, Ministry of Water and Irrigation is seeking alternatives for treating septage and sludge in a separate treatment plant. In any case, biodegradation kinetics (anaerobic and aerobic) are basic important parameters that should be measured for septage in order to specify design criteria of biological treatment units.

2. Septage and Sludge separate treatment

Un-sewered populated areas in Amman are currently using cesspools with variable volumes for wastewater collection and preliminary treatment. When the pool becomes full, special tankers are used to discharge wastewater (supernatant) and sometimes solids (sediments) from the pool as shown in Figure (4), which are then transferred to Ain-Ghazal pre-treatment facility. As the Ministry of Water and Irrigation are planning to have a separate treatment plant for the collected septage, an accurate characterization is a prerequisite for a successful design. Characteristics of septage could be highly variable, even for the same region, and depends on many factors including households habits, water supply characteristics, climatic and geological conditions, piping material, water conservation fixtures (Solomon *et al.*, 1998), household chemicals, volumes of cesspools available and intervals at which septage is discharged. These parameters are also important in determining the physical, biological and chemical characteristics of the discharged septage, and explain the variability in the measured parameters. An example of septage characteristics in Jordan together with range values are shown in Table 1 and Table 2 respectively. The average concentrations of the COD, BOD and TSS for 15 samples collected from different places in Jordan (Table 1) were 3419 mg/l, 1356 mg/l and 4116 mg/l, respectively with standard deviations of 4578 mg/l, 1326 mg/l and 4333 mg/l, respectively. The very high standard deviations obviously show that the numbers of collected samples are not statistically representative to characterize septage and that

Figure 4: Appearance of septage collected from tankers discharging to the decentralized septage treatment plant at Tal Al Mantah (January 2005).

Table 1: Septage characteristics for rural areas in Jordan, ECODIT (2005)

Sample No.	pH	Temp.	COD mg/l	BOD mg/l	TSS mg/l	VSS mg/l	TDS mg/l	NH3 mg/l	NO3 mg/l	TFCC MPN/100ml	nematodes Egg/l
1	7.18	25.0	2562	1325	1226	833	1382	196	5.0	4×10^{6}	0.0
2	7.51	21.5	941	600	544	376	3182	40	45.3	1.1×10^{6}	
3	7.50	23.0	1778	725	602	504	1322	175	2.0	2.3×10^{7}	0.0
4	7.25	23.4	1741	450	1362	984	1980	51	37.8		10.0
5			2319	1259	740						
6			1193	682	636						
7			774	489	455		1042				
8			19100	5675	16898		1080				
9			3555	1472	6367		1089				
10			5055	3201	7465		1044				
11	7.05		4990	360	9110	5660	3820	279	33.8		
12	7.57		462	160	381	190	956	59	5.2		
13	7.03		647	185	1370	350	1200	75	10.0		
14	8.20		3349	1059	6830		1594				
15	7.40		2826	2115	5266		1472				

more samples should be collected. In addition, seasonal changes in septage characteristics are usually not taken into account mainly due to the limited time given for characterization before septage management options are discussed. It should be emphasized that accurate characterization is critical in septage management and final disposal, especially when septage is treated in a separate treatment plant, which is classified as the most expensive available management option (EPA, 1994). As an example, septage with high concentration of relatively stabilized solids should not be treated using biological systems, obviously because no further biodegradation is expected. Assuming that VSS/TSS can be used as indication for solids stability, and referring to values presented in Table 2, it can hardly be decided whether biological treatment should be applied. A VSS/TSS value of 0.3 indicates stabilized solids with expected very limited further biodegradation, while a value of 0.6 indicates solids that may undergo further biodegradation. This confusion, which considerably affects decisions needed for designing a septage treatment plant, holds for many other parameters presented in Table 2 and having wide range of concentrations. Another important example is related to ammonia concentration, which reads normal values that are close to concentrations reported for sewage and up to concentrations that are considered toxic for micro-organisms and algae. This will be of special importance when facultative ponds are proposed for septage treatment. Moreover, salinity

Table 2. Range of concentration for different parameters measured for Septage in Jordan

Parameter	Unit	Value for septage*
pH		6.7-8.4
EC	µs/cm	1675-24700
BOD_5	mg/l	110-8250
COD	mg/l	392-38812
TSS	mg/l	381-10256
TVSS	mg/l	190-6030
TVSS/TSS		0.3-0.6
NH_4-N	mg/l	59-617
Total Coliform	MPN/100ml	1.4×10^{3}-3.0×10^{7}
Fecal Coliform	MPN/100ml	4.0×10^{3}-3.0×10^{7}

* Data obtained from COMEX consultants (1999)

becomes an issue when considering the final effluent disposal. Referring to salinity values measured for samples collected from different tankers in Jordan and ranging between 1675-24700 µs/cm, it cannot be decided whether the effluent can be reused for irrigation or not. Other important parameters, which were rarely –if ever- tested, include anaerobic and aerobic biodegradability, lipids content, settling characteristics; e.g. rate(s) of settling, COD and BOD fractionation, e.g. suspended COD, dissolved COD, suspended BOD and dissolved BOD, heavy metals content and trace organic pollutants. All these parameters are very important in determining treatment techniques and/or design criteria for treatment units.

As a summary, adequate number of measurements made on representative collected samples during summer and winter conditions is very important before discussing septage feasible management options. In addition, biodegradation rates should be determined under aerobic and anaerobic conditions in order to specify best design criteria, namely SRT needed to obtain best conversion identified by the EPA as 38% volatile solids reduction. In most cases previous septage characterization studies in Jordan have ignored the effect of seasonal variations on characteristics. Quantities and qualities of septage will be affected by the extent of storm water or groundwater infiltration to the cesspool. Of special interest, septage discharging at Ain-Ghazal had never been characterized (WAJ, 2006b) and there is an urgent need for characterization especially after the decision made by SPC prohibiting septage and sludge discharges to Khirbit As-Samra treatment plant.

OBJECTIVES

The previous discussion defines the objectives of the current proposed research as follows:

1. Detailed characterization of septage and sludge discharging at Ain-Ghazal pre-treatment facility based on statistically sound number of analysis. Septage characteristics will include 'conventional' parameters like COD, BOD, TSS, pathogens, but also some other important parameters like settling characteristics, COD and BOD fractions, lipids content and heavy metals.
2. Investigating the effect of seasonal variations on the aforementioned septage characteristics.
3. Measuring anaerobic and aerobic biodegradability and biodegradation rates of organic matter.

MATERIALS AND METHODS

A. Mixed septage and sludge samples were collected from tankers discharging at Ain Ghazal pre-treatiment facility. Composite sample over 12 hrs were collected 15 m downstream from discharging points. That was found to be the only feasible sampling point at the location. Based on WAJ, (2006b) records, there exists 135 tanker registered and licensed to dump at Ain Ghazal site. Each of them discharges three to four times per day. Collected composite samples were transferred to the laboratory for analysis. At the site, temperatures of composite samples were measured, while all other parameters were measured at laboratory according to procedures described by the APHA (1995). Samples were analyzed for electrical conductivity (EC), pH, total solids (TS), volatile solids (VS), total suspended solids (TSS), volatile suspended solids (VSS), settleability, total chemical oxygen demand (COD_{tot}), suspended chemical oxygen demand (COD_{ss}), soluble chemical oxygen demand (COD_{sol}), total biochemical oxygen demand (BOD_{tot}), soluble biochemical oxygen demand (BOD_{sol}), total kjeldahl nitrogen (TKN), ammonia (NH_4^+), total phosphorus, sulphate, alkalinity, lipids, total coliforms, fecal coliforms, nematode eggs and heavy metals. Three composite samples during winter and three composite samples during summer were analyzed for Iron (Fe), Zinc (Zn), Manganese (Mn), Cadmium (Cd), Copper (Cu), Lead (Pb) and Nickle (Ni).

B. Anaerobic biodegradability: composite septage sample was collected over 7 days in the period January 3-16,2008. Two series of batches were prepared to examine anaerobic biodegradability of total and paper filterable septage samples at 37^{o}C. Each series of batches contained 7 serum flasks with 0.5 L capacity each. Each serum flask was filled with 0.47 L of septage, 1 ml of trace elements, 1 ml of macronutrients, 0.1 g of yeast, and 10ml of phosphate buffer as described by Van Lier (1995). After closing the flasks, the headspace was flushed for 3 minutes with nitrogen gas in order to create anaerobic environment. The flasks were then incubated at 35^{o}C. At bottle was opened after a certain period of time and analysed for COD_{tot}, COD_{sol} and volatile fatty acids. Biogas production was measured using a digital manometer, while biogas composition was measured using a Philips PU 4500 gas chromotograph with thermal conductivity detector.

C. Aerobic biodegradability: One series of 5 batches was prepared for measuring aerobic biodegradability of a septage sample collected over a day (9 hrs). Septage was first pre-aerated for 2 hrs before starting the experiment in order to enhance aerobic conditions. Each batch contained air diffuser that was operated over the whole experimental period. Each batch consisted of 150 ml of sample incubated at 35^{o}C. Every day, one batch was used for the BOD_5 test and the contents were then discarded. Reduction of the BOD_5 was then measured with time and the rate of aerobic biodegradation was calculated.

RESULTS AND DISCUSSION

Part 1. General characteristics: The average water temperature was 18.5^{o}C for winter and 21^{o}C for summer. Fortunately, water temperature did not drop below 16^{o}C during winter. The pH averaged 7.27 during winter and 7.47 during summer. Three samples had pH values that exceeded 9.0, which is unfavourable when biological treatment of septage is considered. In general the septage is well buffered. The average values calculated for alkalinity were 1392 mg/l and 1510 mg/l for winter and summer respectively. Septage is characterized by high EC value averaging 6226 µs/cm during winter and 5626 µs/cm during summer. This is equivalent to approximate TDS values of 4171 mg/l and 3769 mg/l for winter and summer, respectively. These values will be a major concern if septage has to be treated and reused for irrigation. The maximum allowable limit for the TDS is 1500 mg/l when treated wastewater is to be reused for irrigation according to the Jordanian Standards (893/2006). All values for measured parameters are presented in Appendicies A through E. The average concentrations of TS, VS, TSS and VSS for septage discharging at Ain-Ghazal pre-treatment facility are shown in Figure 5. Septage had almost double concentration of TS during summer than during winter most probably due to dilution effect of rain water during winter. It should be mentioned here that in some cases TS was underestimated probably due to the presence of some volatile materials. This can be seen when testing results of TS and EC –that can be converted into TDS- in Appendix A. TSS average concentration was calculated to be 1613 mg/l during winter and 2117 mg/l during summer. The volatile fraction of the TSS represent 57% and 52% for winter and summer respectively (Figure 5). The volatile suspended solids comprise 30-60% of the TSS in digested primary sludge (Metcalf&Eddy, 2003).

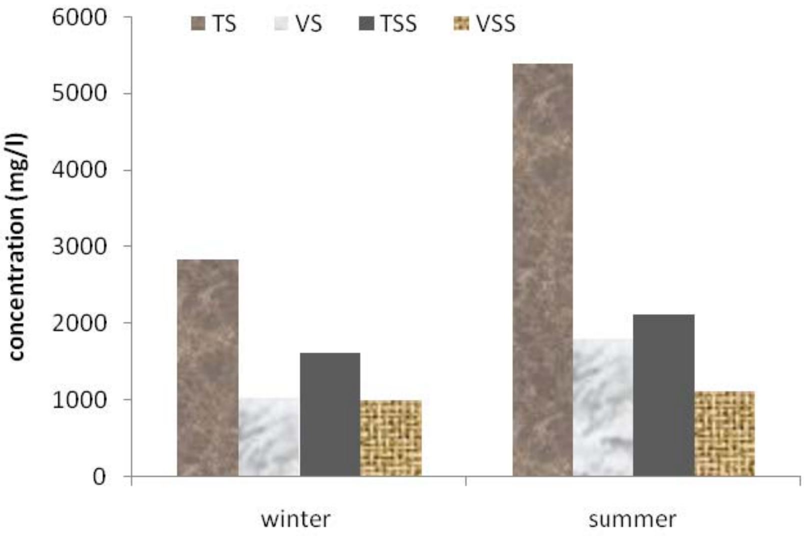

Figure 5. Average TS, VS, TSS and VSS for analysed samples during winter and

Detailed information about biodegradability will be known after terminating the aerobic and anaerobic biodegradation rates set as batch experiments in the labs of WERSC. Related to the physical characteristics of wastewater is the SVI, which had average values of 106 and 90 ml/g TSS for winter and summer respectively. Based on these values, and according to Metcalf & Eddy (2003), sludge has good settling characteristics at SVI of 100 ml/gTS).

The average concentrations of organic pollutants represented by total COD and BOD and their fractions for winter and summer are shown in Table 3. The average total COD was found to be 2.16 times higher during summer compared with winter time with average values of 6425 and 2969mg/l for summer and winter respectively (Figure 6). The considerable seasonal variation could be a result of several factors including the dilution effect of rain water during winter especially that cesspools are not lined and infiltration could take place. A considerable fraction of the COD is found in the suspended form with higher percentage reported during winter (71%) compared with summer (57%). It should be noted that the number of samples analysed for COD_{ss} and COD_{dis} fractions were lower during winter compared with number of samples analysed during summer. Consequently, a less accurate figure could have been resulted for the COD_{ss} fraction during winter. In general, the average COD concentrations calculated for septage discharging at Ain Ghazal pre-treatment

Table 3. Organic constituents of the septage discharging at Ain-Ghazal. Values between brackets are standard deviations

Parameter	COD_{tot} mg/l	COD_{ss} mg/l	COD_{ss}/ COD_{tot} (%)	COD_{dis} mg/l	$BOD_{5\,(tot)}$ (mg/l)	$BOD_{5\,(sol)}$ (mg/l)
Winter time	2969 (1683)	2132 (1361)	71 (19)	484 (113.2)	1532 (509)	857 (232)
Summer time	6425 (3331)	2869 (3286)	57 (18)	1949 (803)	2179 (512)	1344 (421)

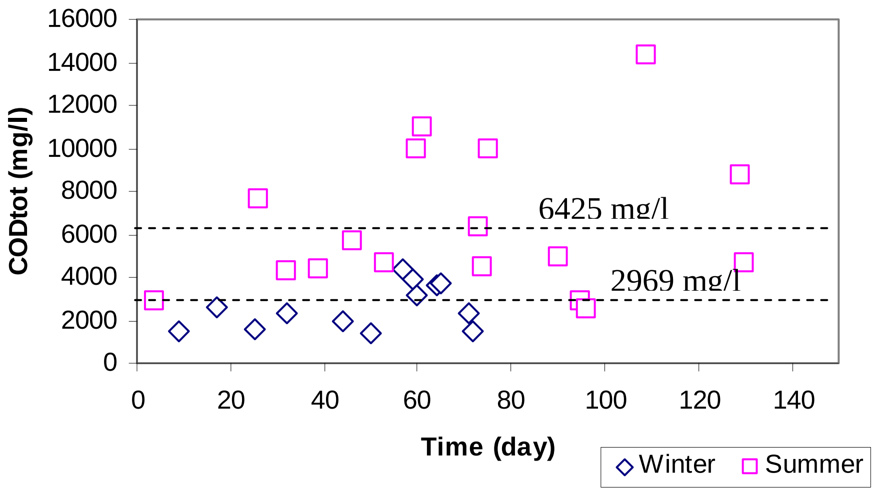

Figure 6. Seasonal variations in influent COD_{tot} concentration for septage discharging at Ain-Ghazal

facility is much lower compared with 31900 mg/l reported for the USA (Crites and Tchobanoglous, 1998). However, the measured parameters for this study showed a lower discrepancy reflected by standard deviations compared with values reported in other locations in Jordan as shown in Table 3 above. Based on the previous results and an average flow rate of 7000 m3/d, septage discharging at Ain Ghazal pre-treatment facility contributes to 7.0-13% of the organic load reaching Khirbit As-Samra treatment plant. Calculations are based on flow rate to Khirbit As-Samra treatment plant averaged 200,000 m^3/d for the year 2006, and an average COD concentration of 1500 mg/l.

The $BOD_{5(tot)}$ represents 45% of the total COD during both winter and summer time, which lies in the range 30-80 % reported for sewage (Metcalf & Eddy, 2003) indicating that the septage could be still biodegradable (most probably the soluble fraction). The $BOD_{5(sol)}$ represents 58% and 56% of the $BOD_{5(tot)}$ for winter and summer, respectively, indicating that a considerable fraction of the BOD can be biodegraded.

The average concentration of lipids in septage was found to be 143 mg/l during winter and 223 mg/l during summer (Table 4). It should be mentioned that sewage in Jordan contains around 150 mg/l of lipids (Halalsheh, 2002), which means that septage contains slightly higher concentrations of this polymer during summer. The reason behind the higher concentration is not clear. However, it could be possible that scum layers that are usually formed in cess pools have higher thickness during winter and are not removed by tankers. Scum layers may contain as twice higher concentration of lipids as compared with solids accumulating in the reactor (Halalsheh *et al*., 2005).

Table 4. Average concentrations of lipids, total nitrogen and ammonia for septage discharging at Ain-Ghazal during winter and summer, 2007

	Lipids (mg/l)	Tkj-N (mg/l)	Ammonium NH_4^+ (mg/l)
Winter	147 (86)*	456 (217)	121 (65)
Summer	223 (55)	248 (148)	106 (46)

* Values between brackets represent standard deviation

The TKN had higher concentrations during winter compared to summer as shown in Table 4. The calculated values are much higher compared with 114 mg/l measured for domestic sewage (Halalsheh, 2002). The higher concentrations could be attributed to the excess biomass collected daily from wastewater treatment plants and discharging at Ain-Ghazal. However, it is difficult to explain the higher concentrations of nitrogen measured during winter compared with summer.

An attempt was made to perform a mass balance on COD assuming conversion factors (Equations 1 and 2) reported for sewage (Miron *et al*., 2000). However, applying these equations on values presented in Table 4 show that these factors does not seem to apply for septage. The calculated $COD_{protein}$ value is higher than the total COD, which is impossible. Additional measurements have to be performed on the extracted lipids in order to calculate their COD values. In addition, protein should be measured directly using different analysis techniques for better estimation of the conversion factor.

$$COD_{lipids} \text{ (mg COD/l)} = \text{Lipids concentration (mg/l)} \times 2.91 \qquad \dots (1)$$

$$COD_{protein} \text{ (mg COD/l)} = \underbrace{\overbrace{((\text{Tkj-N- ammonium})/0.16)}}_{\text{Conversion to proteins}} \times 1.5 \qquad \dots (2)$$

A significant concern to biological treatment of septage discharging at Ain-Ghazal is the high average concentration of sulphate observed during the summer period, which was calculated to be 581 mg/l. This value is considerably higher than the average sulphate concentration during winter with an average of 135 mg/l. The very high concentration of sulphate during summer could be attributed to seasonal industrial discharges, or dissolution of sulphate present in surrounding soil of the cesspool. The later could be higher during summer time as no dilution is expected from rain water. Sulphate can be reduced under anaerobic conditions into sulphide, which is known to be toxic to microorganisms at concentrations of 200 mg/l (Crites *et al*., 1998).

With respect to pathogenic loads, it was found that septage contained considerable counts of total and fecal coliforms with average values of 1.8×10^{10} MPN/ml and 2.2×10^{9} MPN/ml respectively during the winter and 1.2×10^{13} MPN/ml and 1.1×10^{13}

MPN/ml respectively during the summer. These values are higher than those reported else where in Jordan (Table 2). Detailed results are presented in Appendix D. It is also clear that the higher the organic load of septage, the higher total and fecal coliform counts as evidenced by comparing summer with winter values. Nematode eggs were also present with average concentrations of 98 and 87 eggs/l for winter and summer, respectively. It should be mentioned that total and fecal coliform counts as well as nematode eggs concentrations are much higher compared with results presented earlier by COMEX (1999) and ECODIT (2005) as shown in Tables 1 and 2.

Heavy metals concentrations are shown in Table 5. Fortunately the measured elements were present at very low concentrations compared with those reported for septage in the USA and the EPA mean (Crites and Tchobanoglous, (1998).

Table 5. Heavy metals concentration of septage discharging at Ain-Ghazal compared with values collected from USA and EPA mean

Element	Winter mg/l	Summer mg/l	EPA mean* mg/l	US mean* mg/l
Zn	1.76	5.33	49	27.4
Cu	0.72	0.36	6.4	8.27
Mn	0.64	1.19	5.0	3.97
Cd	ND	0.18	0.71	0.27
Ni	0.04	0.61	0.9	0.75
Fe	53.59	6.19	200	191
Pb	1.00		8.4	5.2

* Crites and Tchobanoglous, (1998)

Part 2. Anaerobic biodegradability of septage:
Hydrolysis, acidification and methanogenesis in relation to sludge retention time are shown in figure 8. Biodegradability of septage was measured to be 74% after 80 days of biodegradation at 35^{o}C. Biodegradability of influent to Khirbit Asamra treatment plant was found to be 56% after 130 days of digestion at 25^{o}C, while biodegradability of sewage discharging at Abu-Nusier wastewater treatment plant was found to be 76% after 130 days of incubation at 25^{o}C (Halalsheh, 2002). Sewage biodegradability in Bennekom- The Netherlands was measured to be 21% after 43 days and increased to 74% after 135 days of digestion at 30^{o}C. It should be mentioned that no literature is available describing anaerobic biodegradability of septage, which makes it difficult to

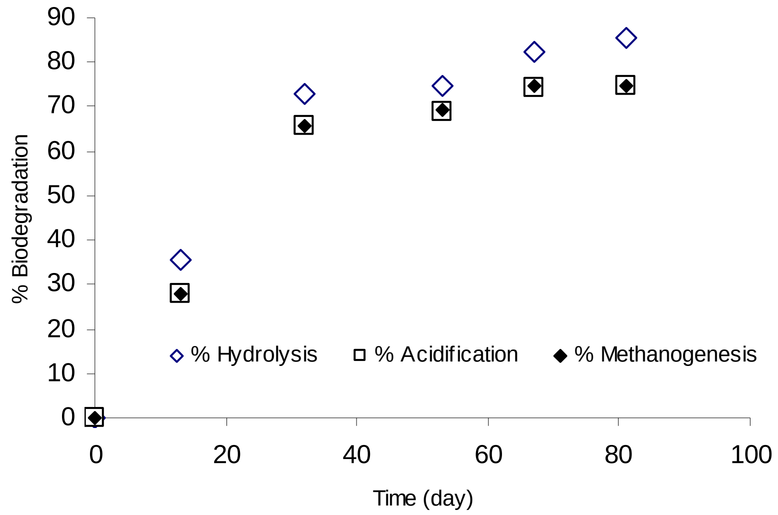

Figure 8. Anaerobic biodegradation of septage discharging at Ain Ghazal pre-treatment facility.

compare the herein obtained results. In comparison with data available for sewage anaerobic biodegradability, it can be concluded that septage also has high anaerobic biodegradability potential. However, the rate of biodegradation of septage is lower compared with sewage. The biodegradation rate followed a first order reaction kinetics with hydrolysis rate constant of 0.024 d^{-1} and relatively good correlation (R^2= 0.91). The hydrolysis rate constant was measured for primary sludge in Palestine and found to be 0.113 d^{-1} at 35^oC (Mahmoud, 2002), which is much higher compared with hydrolysis rate constant calculated for septage in this study. This result is expected when taking into consideration the septage source. Septage consists of fecal matter discharged from cesspools, which already went through some biodegradation of easily biodegradable material. In addition, septage contains excess activated sludge discharged from 5 wastewater treatment plants.

Part 3. Aerobic biodegradability of septage.

Aerobic biodegradation of septage is shown in figure 9. High biodegradability of 96% was measured for spetage at 35^oC. However, the corresponding COD reduction was measured to be only 48% after 7 days of digestion. It should be noted that the remaining COD is still high with a value of 5236 mg/l. COD/BOD was calculated to be 4.3 for at the beginning of the experiment and 52 at the end of the experiment. Hydrolysis rate constant was calculated to be 0.46 d^{-1} at 35^oC and 0.11 d^{-1} at 20^oC assuming that Q = 1.1.

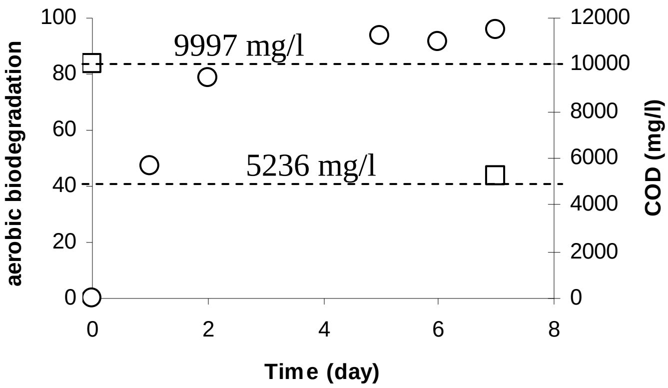

Figure 9. Aerobic biodegradation of septage at 35°C.

CONCLUSIONS

Septage discharging at Ain-Ghazal pre-treatment facility had different concentrations of pollutants during winter compared with summer. The average total COD was found to be 2.16 times higher during summer compared with winter time with average values of 6425 and 2969mg/l for the summer and winter respectively. The $BOD_{5(tot)}$ represents 45% of the total COD during both winter and summer. The ratio VSS/TSS had average values of 0.57 and 0.52. High EC values averaging 6226 μs/cm and 5626 μs/cm for winter and summer, respectively were measured for septage. Samples also contained high counts of Total and fecal coliforms with average values of 1.8×10^{10} MPN/ml and 2.2×10^{9} MPN/ml, respectively during winter and 1.2×10^{13} MPN/ml and 1.1×10^{13} MPN/ml, respectively during summer. Nematode eggs were also present with high concentrations averaging 98 and 87 eggs/l for winter and summer, respectively. Heavy metals concentrations were found to be lower compared with values reported for the USA and EPA as shown in the report. Septage had a high anaerobic biodegradability of 74% after 80 days of digestion with a hydrolysis rate constant of 0.024 d^{-1}. Aerobic biodegradability was 96% at 35°C after 7 days of degradation with a hydrolysis rate constant of 0.46 d^{-1} at 35°C and 0.11 d^{-1} at 20°C. However, results also showed that COD in the aerobic biodegradability experiment was only reduced by 48% with a remaining value of 5236 mg/l.

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APPENDIX A

Physical characteristics and non metallic constituents of spetage discharging at Ain-Ghazal pre-treatment facility

(A) Winter time

Date	Temp.	pH	EC µs/cm	TS mg/l	VS mg/l	TSS mg/l	VSS mg/l	Alkalinity mg/l as $CaCO_3$	Sulfate mg/l
11/02/2007	18	8.79	10210	900	108				
20/02/2007	20	7.18	7201	785	154				
21/02/2007									108
28/02/2007	18	9.27	10360	981	244				170
08/03/2007	20	7.19	3512	788	135			1479	
12/03/2007	18	6.58	6345	850	130			4892	58
15/03/2007	18	7.25	7321	828	133				127
19/03/2007	19			871	103			2349	
27/03/2007	22	6.89	3190	7195	4372	4230	2940	1312	140
02/04/2007	20	6.85	3610	4601	2061			2298	88
09/04/2007	20	7.1		4739	2775	3015	1930	1531	
11/04/2007	18	6.71	5980			1455	770	1068	
12/04/2007	16.5	6.77	6260			970	560	1129	229
16/04/2007	17	6.89	4410	3115	475	400		1647	156
17/04/2007	16	7.55	5350	4600	1590	815	355	927	
23/04/2007	18.5	6.91				995	520	1312	
24/04/2007	16	7.19				510		213.5	
01/05/2007	18.5					350			
Average	18.4	7.27	6146	2521	1023	1416	1179	1680	135
StDev	1.6	0.76	2386	2239	1395	1332	1032	1163	53
Max.	22	9.27	10360	7195	4372	4230	2940	4892	229
Min.	16	6.58	3190	785	103	350	355	214	58

(B) Summer time

Date	Temp.	pH	EC µs/cm	TS mg/l	VS mg/l	TSS mg/l	VSS mg/l	Alkalinity mg/l as $CaCO_3$	Sulfate mg/l
3/05/2007	25								
7/05/2007	30			4370	1706	1095			
29/05/2007	19.5			6538		3907	600	1435	
4/06/2007	18.2	6.62	5900	4706	1597	1265		1806	534
11/06/2007	21.8	9.68	4500	5600	1968	3745	1880	878	
18/06/2007	21.3	6.86	6671	6538	1630	1605	380	3294	
25/06/2007	27.3	7.25	4640	4427	2100	1960	1150	2562	797
2/07/2007	22.5	7.54	9980	8760	1738	1685	755	1403	
3/07/2007	22.7	6.99	8560	5173	2583	4100	2925	1159	823
15/07/2007	21.2	7.43	5960	6084	2559	2265	1320	1684	
16/07/2007	21.1	7.43	6110	5965	1538	1085	305	1952	
17/07/2007	19.4	7.23	7760	10846	3751	4995	2200		
1/08/2007	24.7	7.54	4990	4656	1350	1460	745	1049	474
6/08/2007	19.3	7.18	3530	3686	1748	1590	1090	1385	591
7/08/2007	22.7	6.94	3020	2131	795	490	385	992	266
20/08/2007	20.4	9.36		6031	1422	1825	1180	1013	
9/09/2007	16.3	7.61	3280	3247	1254	1860	1290	1083	
10/09/2007	20.5	6.47	3860	2826	1051	1053	617	952	
Average	21.9	7.48	5626	5387	1799	2117	1121	1510	581
StDev.	3.3	0.90	2077	2132	706	1276	738	675	209
Max.	30.0	9.68	9980	10846	3751	4995	2925	3294	823
Min.	16.3	6.47	3020	2131	795	490	305	875	266

Appendix B

Organic loads of spetage discharging at Ain-Ghazal pre-treatment facility

(A) winter time

Date	CODtot mg/l	CODss mg/l	CODdis mg/l	BODtot mg/l	BODdis mg/l	BOD/COD	CODss/CODtot
11/02/2007							
20/02/2007	1489	546	532				0.37
21/02/2007							
28/02/2007	2609	1978					0.76
08/03/2007	1546						
12/03/2007							
15/03/2007	2284	1727	411				0.76
19/03/2007			183				0.91
27/03/2007	1991	1807		1250			0.68
02/04/2007	1424	963		800		0.56	0.81
09/04/2007	4363	3546		1700	800	0.39	
11/04/2007	3941			1750	1250	0.44	
12/04/2007	3126			1500	750	0.48	
16/04/2007	3638			1200	500	0.33	
17/04/2007	3714			1700	800	0.46	
23/04/2007	2310			1200	1000	0.52	
24/04/2007	1469			1350	900	0.92	
01/05/2007				1600			
Average	2608	1761	375	1405	857	0.51	0.72
St.Dev	1043	1034	177	301	232	0.18	0.19
Max.	4363	3546	532	1750	1250	0.92	0.91
Min.	1424	546	183	800	500	0.33	0.37

(B) Summer time

Date	CODtot mg/l	CODss mg/l	CODdis mg/l	BODtot mg/l	BODdis mg/l	BOD/COD	CODss/CODtot
3/05/2007				2700			
7/05/2007	2850	2038	620	2200	2000	0.77	0.72
29/05/2007	7668	4355	1867	2800		0.37	0.57
4/06/2007	4299	2366	1872	1500	1500	0.35	0.55
11/06/2007	4332	835	3140	1750		0.40	0.19
18/06/2007	5692	1895	2508	2250	1750	0.40	0.33
25/06/2007	4680	1603	1194	1750		0.37	0.34
2/07/2007	9967	7325	2627	2500	1600	0.25	0.73
3/07/2007	10981	9607	643	2750		0.25	0.87
15/07/2007	6343	3656	2072	3250	1250	0.51	0.58
16/07/2007	4435			2000		0.45	
17/07/2007	9940						
1/08/2007	4965	1503	1850	2250	1250	0.45	0.30
6/08/2007	2846	307	2097	2100	1250	0.74	0.11
7/08/2007	2517			1750		0.70	
20/08/2007	14307	10729	3319	2250		0.16	0.75
9/09/2007	8782	5712	1998	2000	750	0.23	0.65
10/09/2007	4625	2239	1482	1250	750	0.27	0.48
Average	6425	3869	1949	2179	1344	0.42	0.51
St.Dev	3331	3286	803	512	421	0.18	0.23
Max.	14307	10729	3319	3250	2000	0.77	0.87
Min.	2517	307	620	1250	750	0.16	0.11

Appendix C: Composition of sludge discharging at Ain-Ghazal pre-treatment facility

(A) winter time

Date	Lipids mg/l	Tkj-N mg/l	NH_4^+ mg/l
28/02/2007		228	
08/03/2007		231	
12/03/2007			78.4
15/03/2007		501	77
19/03/2007			
27/03/2007	80	473	37.8
02/04/2007	272	88	28
09/04/2007	103		
11/04/2007	80		
12/04/2007	200	970	200
16/04/2007		816	154
17/04/2007			
23/04/2007		491	179

(B) Summer time

Date	Lipids mg/l	Tkj-N mg/l	NH_4^+ mg/l
29/05/2007		477	
4/06/2007	160	58.6	47.6
11/06/2007			
18/06/2007	200		
2/07/2007	300		
3/07/2007	300		
15/07/2007		262	112
16/07/2007			102
17/07/2007		116.5	98
1/08/2007	200		
6/08/2007	200	295	123
7/08/2007		281	190
10/09/2007	200		

Appendix D

Pathogenic pollutants in septage discharging at Ain-Ghazal pre-treatment facility

(A) winter time

Date	Total coliform MPN/ml	Fecal coliform MPN/ml	Nematode eggs (eggs/l)
15/03/2007		501	80
19/03/2007	1.4E+7	1.4E+7	
27/03/2007	2.2E+8	1.7E+5	
02/04/2007	9.0E+9	2.8E+9	150
09/04/2007			
11/04/2007			
12/04/2007			
16/04/2007	1.6E+10	9.0E+9	80
17/04/2007	3.6E+9	1.7E+9	
23/04/2007	9.0E+10	2.6E+8	
24/4/2007	1.1E+10	1.4E+9	
Average	1.85E+10	1.90E+09	
St.Dev.	2.97E+10	2.85E+09	
Max.	9.00E+10	9.00E+09	
Min.	1.40E+07	501	

(B) Summer time

Date	Total Coliform (MPN/ml)	Fecal Coliform (MPN/ml)	Nematode eggs (eggs/l)
4/06/2007	1.6E+10	1.6E+10	80
2/07/2007	1.6E+11	1.6E+11	
3/07/2007	1.6E+11	1.6E+11	
16/07/2007	1.6E+13	1.6E+13	
17/07/2007	9.0E+13	9.0E+13	100
6/08/2007			80
7/08/2007	3.5E+12	3.5E+12	
20/08/2007	1.7E+10	1.7E+10	
9/09/2007	3.5E+11	3.5E+11	
10/09/2007	2.8E+11	2.8E+11	
17/09/2007	1.6E+13	1.6E+13	
25/09/2007	2.8E+11	2.8E+11	
Average	1.15E+13	1.15E+13	
St.Dev.	2.55E+13	2.55E+13	
Max.	9.00E+13	9.00E+13	
Min.	1.60E+10	1.60E+10	

Appendix E
Heavy metals concentrations for septage discharging at Ain Ghazal pre-treatment facility

(A) Winter

Date	Zn (ppm)	Cu (ppm)	Mn (ppm)	Cd (ppm)	Ni (ppm)	Fe (ppm)	Pb (ppm)
15/07/2007	2.14	0.58	0.69	ND	0.12	24.15	0.94
16/07/2007	1.82	0.24	0.35	ND	ND	69.85	0.94
17/7/2007	1.33	1.35	0.87	ND	ND	66.77	1.13

(B) Summer time

Date	Zn (ppm)	Cu (ppm)	Mn (ppm)	Cd (ppm)	Ni (ppm)	Fe (ppm)
11/04/2007	3.17	0.34	0.75	0.16	0.43	4.11
12/04/2007	2.14	0.49	1.77	0.17	0.58	0.74
16/4/2007	10.67	0.25	1.04	0.20	0.77	13.72