Progress report

Oct. 11, 2007

ANAEROBIC WASTEWATER TREATMENT AT LOW TEMPERATURE IN JORDAN

Submitted to

Badia Research and Development Centre

Submitted by

Water and Environmental Research and Study centre
University of Jordan

ADMINISTRATION AND LOGESTICS

A) Personnel working for the project

Personnel continued working on the project for the period April- October, 2007 as shown in Table 1. Mr. Hussain Muhsen is an MSc student of the environmental management program who already prepared the set up for the activity 4.2 (part 1 of the project) and is working for his thesis on this activity. He will be responsible in the coming period for performing all analysis needed for monitoring the two UASB reactors installed at the experimental station at Abu-Nusier wastewater treatment plant. Mrs Haifa Yazajeen –chemical engineer- took over the work of Mrs Zainab Abu Rumman and is working on feeding all reactors and preparing the feed sludge by sieving and dilution. She will also perform all analysis needed for the sludge operated based on conditions presented in sections 4.3.1, 4.3.2 and 4.3.3 of part 1 of the proposal. Engineer Hanan Nuaimat is working on part 2 of the project and already installed the set up at Za'tary-Salt and did some analysis and monitoring of solids accumulated in the system. She will also be responsible for conducting the lab experiment suggested later in this report.

Table 1. Expenditures on the project for the period Jan 1-April 1, 2007

1	Human Resources	
	Part 1: Adapting UASB reactor for sewage treatment at low temperature	
	Research assistant* Haifa Yazajeen	2676.6
	MSc student Hussain Muhsen**	847.44
	Subtotal	3524.04
	Part 2: Anaerobic biodegradation of cesspool solids under Jordanian conditions	
	Research assistant Hanan Nuaimat*	2676.6
	Human Resources (total)	**6200.64**
2	Materials	
	Part 1: Adapting UASB reactor for sewage treatment at low temperature	
	Additional circulator	1830.99
	subtotal	**1830.99**
3	Consumables	**2500**
4	Travel	**686**
5	University overhead	**2600**
6	Total	13,817

* Research assistants receive a salary of 330JD per month, which is equivalent to 446.1US$.

** MSc student receive a scholarship of 100JD per month, which is equivalent to 141.24US$.

B) Major Equipment acquisition

Although one of the prefabricated insulated cabinets is a controlled room temperature as presented in the first report, the installed air conditioning device was able to maintain the temperature at an average of $18 \pm 2^{o}C$. However, the temperature should be maintained at 15°C. For this reason a circulator was ordered and connected to all reactors operated based on conditions presented in section 4.3.1.

SCIENTIFIC RESULTS

Part 1

<u>Adapting the upflow anaerobic sludge blanket reactor for sewage treatment at low temperature</u>

A. Enhancing hydrolysis by increasing the surface area available for hydrolytic enzymes

This experiment assumes that hydrolytic enzymes are not limiting in the sludge bed and that the most limiting factor affecting hydrolysis is bioavailability of substrate. Increasing surface area by decreasing the average floc size will result in better bioavailability of particles and higher hydrolysis rate. In order to validate this hypothesis, two sets of experiments are designed and operating at 15°C. The first set is operated at methanogenic conditions with SRT of 60 days as shown in Figure 1. This set was started on June 1, 2007 and contains five CSTRs operated at different mixing velocities, namely 250rpm, 300 rpm, 350 rpm, 400 rpm and 450 rpm. During June and July, temperature was kept at 18 ± 2°C, while a refrigerated circulator was installed (upon arrival) on mid August in order to keep the temperature at 15°C. The second set of reactors is operating at 30 days SRT and at the same mixing velocities of the first set. This set started on June 26, 2007. Feed sludge is brought from Irbid and prepared to keep total solids concentration of 20 g/L. The feed was analysed for its compositions and results are shown in Table 1. Every day, a certain amount of sludge is taken out of the reactors and the same amount of the prepared primary sludge is fed to the reactors keeping the sludge retention time at 60 days and 30 days for the first and the second sets respectively. The feed sludge as well as primary sludge is kept at 4°C. In addition, measurement of the PSD of the first set is taking place in order to check that the average particle size is different between the reactors. At the beginning of the experiment, the reactors were operated at lower mixing velocities; however, analysis of the TS in reactors showed that these mixing velocities were not sufficient to operate the system as CSTR. This was indicated by the high TS concentrations at the bottom of the reactors especially those reactors operated at low

Figure 1. first set of reactors operated at five
Different mixing velocities and at 60d of SRT

mixing velocities of 60 and 100 rpm. The mixing velocities were increased in August in order to guarantee sufficient mixing. It should be mentioned that all reactors were supplied with baffles connected to the walls of the reactors in order to prevent dead spaces. The volume weighted average particle sizes D[4,3] based on the first set of analysis are shown in table 2. The average particle size was calculated for the size range of 2.9 – 65.81µm. This range showed a significant effect on the degree of sludge digestion (Halalsheh *et al.*, 2005). The calculated average particle sizes were 41, 38, 40, 36 and 37 µm for reactors operated at 250, 300, 350, 400 and 450 rpm, respectively. It was decided to keep the reactors operating at 250 rpm and 400 rpm at the same mixing velocities and increase the mixing velocities for the other reactor to 550, 700 and 850 rpm. The average particle diameter for these reactors will be measured and calculated within the coming two weeks. The average particle diameter for the reactors operating at 30 days SRT will also be measured in the coming two weeks. However, and referring to the measured total solids concentration, it looks that there is a difference in the degree of digestion between the reactors. The results are still preliminary and will be confirmed the coming month. We expect to reach steady state of these reactors in November since the temperature was fixed at 15^{o}C only on August. The steady state conditions will be assumed at steady VFA concentrations. Different constituents will be measured and biodegradation rates will be calculated.

B. Effect of pH and temperature on hydrolysis

This experiment aims at determining whether low temperature has a direct effect on hydrolysis. According to Halalsheh, (2000), it is not clear whether the low temperature directly affects hydrolysis at a certain SRT or has an indirect effect due to a conjugate lower pH values compared with sludge having the same age and operated at higher temperatures. Two sets of CSTR's are operating at two different meshophilic temperatures, namely, 15^{o}C, 25^{o}C as shown in Figure 2 (shows only one set). Each set consists of 4 reactors operated at 15, 30, 50 and 65 days SRTs. Reactors are fed with primary sludge once per day. This experiment was started on May 1, 2007. Feed sludge characteristics are shown in table 1. Reactors operated at 15 and 30 days SRT are at steady state conditions. Some problems are faced with gas collection and we are trying to control gas leakage. All sludge analysis of reactors operated at 15 and 30 SRT will take place on the third week of October 2007 after which pH will be adjusted at 7.0 and biodegradation rates will be measured again at the adjusted pH at the two temperatures.

Table 1. Analysis performed on the feed sludge

Feed	CODtot g/l	CODss g/l	CODsol g/l	TS g/l	VS g/l	NH4+ mg/l	Carbohydrates gCOD/l	Proteins gCOD/l	lipids gCOD/l	VFA gCOD/l
	31,944	28,244	2341	18	14	140	2.47	10.17	18.46	1.668

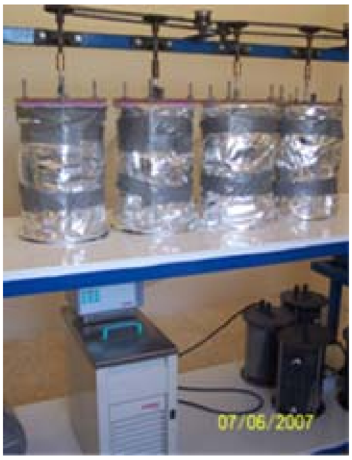

Figure 2. First set operated at 25^{o}C and different SRTs

C. Effect of Lamella plates on sludge concentration in conventional UASB reactors operated at ambient temperatures in Jordan

This experiment aims at optimizing the solids removal and retention in the UASB reactor by modifying the design of a conventional system. The main goal is to achieve lower operating hydraulic retention time. The effect of installing lamella plates at the settling zone and underneath the GLS will be investigated. Two UASB reactors are built at the location of Abu-Nusier treatment plant as shown in Figure 3a. Each reactor has a volume of 3 m^3. Lamella plates, figure 3b, are introduced in the sludge blanket underneath the GSS in one reactor, while plates are introduced in the settling zone in the second reactor. Calculations made to determine number of plates and the space between plates will be supplied in details in the final report. The two reactors were operated on September 10, 2007. The reactors were started up without inoculation. An MSc student, Mr. Hussain Muhsen will be responsible about monitoring both reactors for the removal of different COD fractions and for sludge build up in both systems. Samples will be collected once every two weeks before arriving at steady state conditions and weekly after steady state conditions. Samples will be analysed for parameters presented in the original proposal.

Table 2. Average particle size for reactors operated at 60 days SRT at 15^{o}C

Mixing velocity	250rpm	300rpm	350rpm	400rpm	450rpm
D[4,3] (µm)	41	38	40	36	37

Part 2. Anaerobic biodegradation of cesspool solids under Jordanian conditions

General descriptions of the site and the accumulation system were presented in the previous report. Seven successive composite samples were collected daily over 24hrs and analysed for the COD fractions, total suspended solids (TSS), Volatile suspended solids (VSS), ammonia nitrogen (NH_4^+), lipids, carbohydrates and proteins. Influent characterization took place before starting the operation of the accumulation system on February, which represents wintertime and lately on July representing summer.

Average water temperatures were 14^{o}C and 25^{o}C for winter and summer respectively. Influent general characteristics are shown in table 3. The average total COD was 1733 mg/l and 3073 mg/l for winter and summer respectively. Suspended COD fraction represents only23 and 36% of the total COD during winter and summer respectively.

Figure 3. Two UASB reactors (a) with GLS layers (b) installed at the location of Abu-Busier wastewater treatment plant.

These values are much lower compared with 58-70% reported for domestic sewage in Jordan (Halalsheh, 2002). Soluble fraction of the COD represents 50% and 43% of the total COD as calculated for winter and summer respectively, which can be considered as a considerable fraction compared with domestic sewage.

Table 3. General characteristics of the cesspool influent

Parameter	pH	COD_{tot} mg/l	COD_{ss} mg/l	COD_{col} mg/l	COD_{sol} mg/l	TSS mg/l	VSS mg/l	NH_4^+ mg/l
winter	8	1733	398	511	794	327	263	104
summer	8.2	3073	1161	605	1207	456	402	177

Wastewater composition compared with domestic sewage is shown in Table 4. It should be mentioned that some problems were faced during kj-N measurements probably due to incomplete digestions. Results presented in table 4 are based on one composite sample dated 30/8/2007 and includes organic nitrogen determined as described by (AOAC, 1990) instead of the digestion procedure explained in the APHA, (1995). It should be mentioned that lipids were low in that specific sample. According to 6 measurements performed on collected samples during winter and summer respectively, lipids represent 22% and 17%, respectively. More analysis will be performed to check the composition.

Table4. Average percentages –COD basis- of carbohydrates, lipids and proteins of the influent to the accumulation system compared with domestic sewage

Parameter	Proteins	Lipids	Carbohydrates	VFA
influent to cesspool	62.1	2.92	10.86	11.09
domestic sewage	48	31	5	9

<u>Operation of the solids accumulation system AC</u>

The system had a detention time of 10 days and was operated for the period March, April and May, 2007. After each filling, water was discharged out of the system using a peristaltic pump operated at low rate in order to avoid re-suspension of the settled solids. This practice was performed during April and May. During the operational period, solids concentration was measured at the lowest tap (Figure 4) and at the water surface just below the by pass pipe (Figure 4). A floating layer was always present and the water surface and was the reason behind measuring solids concentration at that specific location. Average solids concentration was 325 mg/l and 2508 mg/l for the lowest tap and just below the by pass pipe, respectively. The AC did not really accumulate solids probably due to the following reasons: Firstly, temperature differentiation between the bottom and the top of the accumulation system. There was always at least a 3°C lower temperature measured at the bottom of the system compared with that measured at the top. This difference in temperature may seriously affect settling of solids in the system. Secondly, lower fraction of the suspended COD may require much longer periods of time in order to allow sufficient time for solids accumulation.

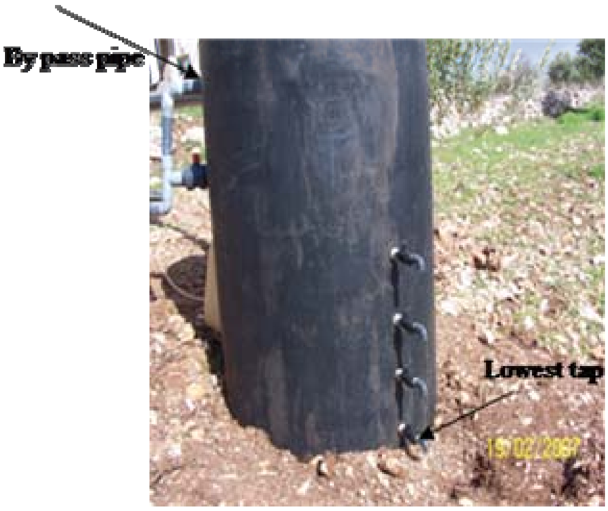

Figure 4. Photo showing the AC with the taps and by pass pipe

In order to solve this serious problem, two modifications on the experiment are suggested:

1. The system will be insulated in order to lower the effect of surrounding ambient temperature, and
2. An additional experiment will be performed at the laboratory as described in the following section.

Additional suggested Lab work

As the main idea from this part was to measure the rate and the degree of biodegradation of the solids accumulated in the cesspools in relation to their age, we think that this experiment can still be conducted and better controlled in the laboratory. Composite wastewater samples will be collected over a week. Half of the collected wastewater will be filtered using 20-25 μm filter papers. Biodegradability and the rate of biodegradation will be measured for the wastewater and for the paper filtered wastewater. In this case, biodegradability of the solids fraction can be calculated as the difference between the total and the paper filtered biodegradability. The following experimental setup is suggested:

Eight series of batches are suggested measuring the biodegradation rates at both 25°C and 14°C as shown in Table 5. The experiment will be conducted using 500 ml serum flasks. Granular sludge will be used as seed sludge in half of the bottles while the other half will be kept without inoculation. Two main reasons are behind this set up. Firstly, it has been reported that lipids are only removed in the presence of methanogenic conditions. In this case, inoculum is important for lipids biodegradation. At the same time proteins and carbohydrates concentrations are very high in granular and are expected to interfere with measurements taken for wastewater. In addition, following protein degradation based only on ammonia production could be misleading as ammonium may undergo chemical precipitation (Miron *et al*., 2000). Proteins and carbohydrates degradation can still occur at acidogenic conditions. In this case, proteins and carbohydrates degradation is better followed without using inoculum.

The experiment will be conducted firstly at 25^{o}C and then repeated at 15^{o}C due to limitations in available number of serum flasks. For each inoculated bottle, 470 ml of wastewater, 12 gm of granular sludge, 1 ml of trace elements, 1 ml of macronutrients, 0.1 gm of yeast, and 10 ml of phosphate buffer will be added. The headspace will be flushed with nitrogen and then bottles will be incubated at the specified temperature. Each time of analysis 4 bottles will be opened (a wastewater sample with inoculum, wastewater sample without inoculum, paper filtered sample with inoculum, paper filtered sample without inoculum). All samples will be analysed for COD fractions, ammonia, VFA. Proteins and carbohydrates will be measured for non inoculated samples, while inoculated bottles will be analysed for lipids. All COD fractions will be measured according to APHA (1995). Paper filtered COD will be determined after filtering the sample using Whatmann No. (40) filter papers. Membrane filtration will be determined after filtering the sample using 0.45μm filter papers. Lipids will be determined after acidifying the contents of the inoculated serum flasks. All contents will be centrifuged and solids will be transferred to extraction thimbles. Sohxlet extraction method will be used as described by APHA (1995). Total nitrogen will be determined using the method described by AOAC, (1990) –not sure yet-. Nitrate, nitrite and ammonium will then be extracted.

Table 5. Suggested experimental set up designed for measuring biodegradability and biodegradation rates of solids accumulated in cesspools in Jordan

Temp (^{o}C)	Use of blank and inoculum	Flask Condition	No. of flasks (Vol. of the flask= 500ml)
14	+	Flasks filled with raw wastewater (with inoculum)	7 + 1 blank
14		Flasks filled with paper filtered wastewater (with inoculum)	7 + 1 blank
14	-	Flasks filled with raw wastewater (without inoculum)	7
14		Flasks filled with paper filtered wastewater (without inoculum)	7
25	+	Flasks filled with raw wastewater (with inoculum)	7 + 1 balnk
25		Flasks filled with paper filtered wastewater (with inoculum)	7 + 1 blank
25	-	Flasks filled with raw wastewater (without inoculum)	7
25		Flasks filled with paper filtered wastewater (without inoculum	

Some questions related to the suggested experiment

1. Protein measurement:

Results obtained for nitrogen for two different samples collected from the cesspool and a composite septage sample from Ain Ghazal pre-treatment facility and using two different methods are shown in Table 6. Higher results were obtained using AOAC (1990), which is commonly used to measure total nitrogen in fertilizers. Nitrate and nitrite were also measured for the sample and were absent. The question is whether this method is used for estimating nitrogen in wastewater. Most of the literature I read measure using methods described by APHA, rather than AOAC. It looks that the later is more accurate.

Table 6. Nitrogen measured using two different procedures

Sample	Kj-N (Cr) AOAC (1990)	Kj-N (Cu) APHA (1995)	NH3 APHA (1995)
cesspool 1	272	213	140
Ghazal 1	202	147	82

Modified work shedule

The expected time frame of work is presented in Table 7.

Table 7. Time frame of the proposed project

Activity	June-November,2007					Nov., 2007-March, 2008		
Effect of PSD on hydrolysis	■	■	■	■	■			
30 days SRT		■	■	■	■			
60 days SRT	■	■	■	■	■	■	■	■
Effect of pH and temp. on hydrolysis	■	■	■	■	■	■	■	■
Effect of gradual changes in temperature in enzymatic activities						■	■	
Modified UASB reactor		■	■	■	■	■	■	■
Report writing								■

REFERENCES

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Miron, Y., Zeema, G., Lier, J.B. van, and Lettinga, G. (2000). The role of sludge retention time in the hydrolysis and acidification of lipids, carbohydrates and proteins during digestion of primary sludge in CSTR's systems. Wat. Res. V ol. 34, No.5, pp. 1705-1713.