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Characterization and Anaerobic Biodegradation of Single House Wastewater

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ABSTRACT

Anaerobic biodegradation and characterization of wastewater produced at household level in rural areas in Jordan were considered in this study in order to investigate the possibility of applying house onsite low cost treatment systems. Results showed that the total chemical oxygen demand (COD_{tot}) was 1.8 times higher during summer than during winter. The average COD_{tot} during summer and winter amounted to 2982 mg/l and 1683 mg/l, respectively. The suspended fraction of the COD represents 41% and 38% of COD_{tot} for summer and winter, respectively. Maximum anaerobic biodegradability of the wastewater was found to be 43% (COD basis) for unseeded samples and 59% for seeded samples after 159 days of digestion at 25°C. Hydrolysis rate constant for the seeded samples was calculated to be 0.006 d^{-1} (R^2= 0.877). Low biodegradability measured for the wastewater was mainly attributed to excessive use of detergents and disinfectants. Accordingly, household habits should be changed before effective biological anaerobic treatment can be considered.

KEYWORDS: Domestic wastewater, Household wastewater, Characteristics, Anaerobic biodegradability, Methanogenesis, Hydrolysis rate constant.

INTRODUCTION

Many countries in the Middle East suffer serious fresh water problems and are continuously looking for unconventional water resources, particularly for agricultural production. Reclaimed wastewater is a potential water source that may substitute fresh water for irrigation. In Jordan, for example, more than 90% of collected and treated wastewater is used for irrigation (Ministry of Water and Irrigation, 2009). However, sanitation services are still limited to 62% of the population (Ministry of Water and Irrigation, 2009) and full utilization of wastewater as an unconventional water resource cannot be achieved. This is mainly due to the current paradigm in sanitation services that basically depends on centralized wastewater treatment systems. Such concepts require costly sewerage systems, which are unaffordable, especially in rural areas where population densities are low (Bakir, 2001). Consequently, rural areas are usually left without adequate sanitation and wastewater is lost and improperly managed. Settlements in rural areas are in many cases served by pervious cesspools. Raw wastewater is discharged into these cesspools, allowing for contaminants to reach groundwater and consequently jeopardizing its quality (Baalousha, 2008; Al-Kuisi et al., 2009). Certainly, the extent of groundwater contamination depends on wastewater characteristics, site's hydro-geological features, soil's characteristics and climatic conditions (Zaporozec,

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2004). Even in locations where cesspools are impervious, regular discharges of septage are needed and cesspool content has to be transferred to a dumping site or to a wastewater treatment plant. This is obviously a burden for low-income households. In order to solve such problems, a shift in sanitation concepts should occur. Decentralized sanitation options are attractive for such cases and wastewater treatment can be provided at small scales (Wilderer, 2001; Parkinson and Tayler, 2003; Libralato et al., 2012; Bakir, 2001) . In fact, many households of rural areas have small farms around their residences and consume considerable amounts of fresh water for irrigating fruitful trees. Accordingly, adopting the approach of wastewater treatment and reuse at household level results in providing a source for irrigation water and in turn reduces water bills.

Technologies that can be considered appropriate for house onsite wastewater treatment have to be sustainable, efficient and reliable, simple, economically affordable and socially acceptable. Systems that comply with the aforesaid criteria include, but not limited to, anaerobic and natural systems, applied separately or connectedly. That is to say, Upflow Anaerobic Sludge Blanket (UASB) reactor, UASB-septic tank, anaerobic baffled reactor, anaerobic filter, constructed wetland and UASB or septic tank followed by sand filter.

Anaerobic systems have the advantage of minimum energy requirements, especially if compared with the conventional aerobic treatment systems, simplicity in operation and production of minimal amounts of sludge. For these main reasons, anaerobic systems are highly recommended for wastewater treatment at household level.

Anaerobic biodegradation proceeds in successive stages; namely: (1) hydrolysis, (2) acidification and (3) methanogenesis. Accordingly, wastewater's characteristics, hydrolysis %, acidification % and maximum anaerobic biodegradability (AB_{max}) that is expressed as methanogenesis % should be formerly determined before discussing feasible anaerobic wastewater treatment options. Wastewater characteristics and anaerobic biodegradability may vary considerably at house level due to variations in household habits and consumption of chemicals. Low anaerobic biodegradability may indicate excessive application of chemicals. In such cases, public awareness is needed before considering treatment alternatives. In spite of the existence of some literature on anaerobic biodegradability of source separated wastewater (Luostarinen et al., 2007; Elmitwalli and Otterpohl, 2007; Zeeman et al., 2008; Hernandez et al., 2011), there is hardly any literature on anaerobic biodegradability of total wastewater produced by a single household. The latter becomes of importance in many cases when separation of different wastewater streams is not practical and the whole wastewater flow has to be treated for reuse purposes. Household habits and consumption of chemicals may also affect wastewater composition and anaerobic biodegradability of COD fractions; namely suspended COD and soluble COD. This is of great importance when considering low cost anaerobic treatment options, especially at low temperatures when hydrolysis of suspended solids is limited. This is to say, under the condition of limited hydrolysis, longer sludge retention time is needed to achieve adequate treatment (Zeeman and Lettinga, 1999). This in turn calls for longer hydraulic retention time (HRT) and consequently for a reactor of a larger volume.

The specific objectives of this research are; *(i)* characterization of wastewater produced by a single house in Za'tari village in Jordan and *(ii)* measurement of maximum anaerobic biodegradability (i.e., methanogenesis %, hydrolysis % and acidification % for household wastewater as the first step before selecting the best low cost house onsite treatment option. Although the present research is applied on a single household, its results can be generalized over the whole village, since most houses have comparable behaviours and water consumption rates.

MATERIALS AND METHODS

General Description. The house is located at Za'tari village in Jordan. It has a total area of 250 m^2, surrounded by a 1750 m^2 farm. The farm is planted with orchards and olive trees. The house is a residence for two adults and four children. Three children are school students. It has three pour flush toilets two of which are in use. Flushing is performed using 2.5 l capacity containers. Children shower at least 4 times per week. Laundry takes place twice per week on the average. Top loading washing machine is used for laundry. The use of laundry detergents range from 0.8-1.6 kg/ capita.yr. The house is not furnished with carpets and floors are daily cleaned with water and detergents. The average amount of detergents used for general cleaning in the house is 4 kg/capita.yr. In addition, 5 l/capita.yr are used for disinfection.

Composite wastewater samples were collected over 24 hs in the period extending from mid February till early September and analyzed for the total COD (COD_{tot}), paper filtered COD (COD_{pf}), soluble COD (COD_{sol}), Volatile Fatty Acids (VFA), total Kjeldahl nitrogen and lipids.

Wastewater Biodegradation Rate. In a separate experiment, wastewater composite samples that were collected hourly over 4 days were used for the purpose of determining the maximum anaerobic biodegradability (AB_{max}), hydrolysis % and acidification % of single house wastewater. Two series of batches were incubated at 25°C (average summer water temperature). The first series consisted of 7 unseeded serum flasks. The second series consisted of 7 seeded serum flasks with an additional blank flask. Set-up for each experiment is shown in Table 1. Each 0.5 l serum flask was filled with 470 ml of wastewater, 12 gram of granular sludge (only for seeded serum flasks), 1 ml of trace elements, 1 ml of macronutrients, 0.1 g of yeast and 10 ml of phosphate. Compositions of trace elements solution, macronutrients and buffer were reported elsewhere (Lier, 1995). After closing the serum flask, headspace was flushed for 3 minutes with nitrogen gas in order to ensure anaerobic conditions. After preparation, serum flasks were incubated at 25°C. At each time of examination, two serum flasks were opened (one of each series) and tested for different constituents. The experiments were stopped after attaining stable production of biogas and that was after 159 days. All measurements made for each serum flask were conducted in duplicates. Each serum flask was analyzed for COD_{tot}, COD_{sol} and Volatile Fatty Acids (VFA). Biogas production was measured using a digital manometer (SPER Scientific). Methane composition was determined using Philips Pye unicam pu 4500 gas chromatograph equipped with a thermal conductivity detector. Carrier gas was helium, and the temperatures of the injector, the column and the detector were: 100, 70 and 200ºC, respectively.

Analytical Methods. COD was measured according to the Standard Method for Examination of Water and Wastewater (APHA, 1995). COD_{pf} was determined after sample filtration using paper filters (Whatmann No.40). COD_{sol} was measured after sample filtration using 0.45-micrometer membrane filters (Orange Scientific). COD_{tot} was fractionated into suspended COD (COD_{ss}), colloidal COD (COD_{col}) and soluble COD (COD_{sol}). The suspended COD was calculated as the difference between COD_{tot} and COD_{pf}. Colloidal COD was calculated as the difference between COD_{pf} and COD_{sol}. VFA, total Kjeldahl nitrogen and lipids were analyzed according to Standard Methods for Examination of Water and Wastewater (APHA, 1995). Lipids were analyzed using sohxlet extraction method by petroleum ether. Carbohydrates were determined by phenol-sulfuric acid method with glucose as a standard (Bardley et al., 1971).

***Calculations* and Conversions**

Maximum anaerobic biodegradability (AB_{max}), percentage of hydrolysis (H%) and percentage of acidification (A%) for seeded samples were calculated according to the following equations:

$$AB_{\max} = (\frac{CH_{4COD_{sample}} - CH_{4COD_{blank}}}{COD_{tot_{t=0}}})*100 \quad (1)$$

$$H\ (\%) = (\frac{(CH_{4COD_{sample}} - CH_{4COD_{blank}}) + (COD_{dissolved_t} - COD_{dissolved_{t=0}})}{COD_{tot_{t=0}} - COD_{dissolved_{t=0}}})*100 \quad (2)$$

$$A(\%) = (\frac{(CH_{4COD_{sample}} - CH_{4COD_{blank}}) + (COD_{VFA_t} - COD_{VFA_{t=0}})}{COD_{tot_{t=0}} - COD_{VFA_{t=0}}})*100 \quad (3)$$

Table 1. Experimental set-up for the biodegradation experiment

Wastewater	Flask condition	No. of flasks
Raw	Flask with granular sludge as inoculum	7 serum flasks + 1 blank flask
Raw	Flask without inoculum	7 serum flasks

For unseeded samples, equations 1,2 and 3 are applicable with $CH_{4COD_{blank}} = 0$.

Conversions. *1g lipids=2.91gCOD* (Sayed, 1987)*; 1g protein=0.16g Nkj=1.5gCOD* (Miron et al., 2000) *and 1g carbohydrates=1.07gCOD* (Sayed, 1987).

RESULTS AND DISCUSSION

The average water consumption as measured during summer was 41 l/c.d. A separate line was providing water for irrigation, terrace cleaning and other outdoor water uses. The average outdoor water consumption was measured to be 700 l/d. Total water consumption was 158 l/c.d which is higher compared with 110 l/c.d estimated for Amman, the Capital of Jordan. The high outdoor water consumption emphasizes the need for better management of wastewater that is currently collected in cesspools and can be a potential water source when properly treated. Wastewater production averaged 27 l/c.d and 33 l/c.d for winter and summer, respectively. Wastewater production corresponds to 81% of the average indoor water consumption during summer. Measured COD fractions of the wastewater during both winter and summer are shown in Table 2. The average COD_{tot} concentration during summer is 1.8 times higher compared with the average concentration measured during winter. The higher COD concentration during summer could be attributed to the higher kitchen activities resulting from frequent social activities. The suspended fraction of the COD represents 38% and 41% of COD_{tot} for winter and summer, respectively. The COD_{ss} fraction measured for the single house wastewater is considerably lower compared with that measured for Abu-Nusier decentralized wastewater treatment plant with an average of 53% (Halalsheh et al., 2010). Soluble fractions of the COD for the single house wastewater represent 46% and 40% of COD_{tot} for winter and summer, respectively. The soluble fraction of the total COD was calculated to be 33% for Abu-Nusier wastewater treatment plant (Halalsheh et al., 2010). The higher COD_{sol} fraction could be due to the application of detergents that are daily used for different purposes including floor cleaning. It should be mentioned that no literature was available for household wastewater COD fractionation, which renders comparison with other values difficult. Available literature performs characterization based on source separated wastewater.

Table 2. Seasonal variations in COD fractions of household wastewater

Season	COD_{tot} mg/l	COD_{ss} mg/l	COD_{col} mg/l	COD_{sol} mg/l
Winter	1683	517	405	780
Summer	2982	1233	572	1181

Table 3. Composition of single house wastewater compared with values reported for decentralized and centralized treatment plants in Jordan

Wastewater source	Lipids (% of COD_{tot})	Carbohydrates (% of COD_{tot})	Proteins (% of COD_{tot})	Reference
Single house/Za'tari	29	5	34	This study
Abu-Nusier treatment plant influent	31	5	48	Halalsheh (2002)
Khirbit As-samra treatment plant influent	23	5	45	Halalsheh (2002)

Table 4. Biodegradability of the single house wastewater compared with other wastewater sources

Wastewater	Temp. (°C)	AB_{max} (%) COD basis	Experimental time (days)	Use of seed	Reference
Raw sewage (Bennekom/ The Netherlands)	20 20 30 30	74 8 74 24	135 43 135 43	not seeded	Elmitwalli et al. (2001)
Raw sewage (Egyptian villages) Raw sewage(Egyptian cities) Suspended COD fraction (Egyptian villages and cities)	24-34 24-34 24-34	73 66 73-74	121 121 121	not seeded	Elmitwalli et al. (2003)
Raw sewage (Amman-Jordan)	25	76	130	not seeded	Halalsheh (2002)
Raw sewage (Palestine)	30	32-49	61		Mahmoud et al. (2003)
Grey water (Luebeck, Germany) Suspended fraction of grey water (Luebeck, Germany)	30 30	121-125 121-125	74 70	not seeded	Elmitwalli and Otterpohl (2007)
Single house raw wastewater Single house raw wastewater	25 25	59 43	159 159	seeded not seeded	This study

Wastewater composition in comparison with influent to some treatment plants in Jordan is shown in Table 3. Obviously, the single house wastewater contains less protein compared with the influent to

Abu- Nusier and Khirbit As-Samra wastewater treatment plants. Proteins constitute 34%, 48% and 45% of the single house wastewater, influent to Abu-Nusier wastewater treatment plant and influent to Khirbit As-Samra wastewater treatment plant, respectively. Proteins, lipids and carbohydrates represent 69% of the single house wastewater COD_{tot}.

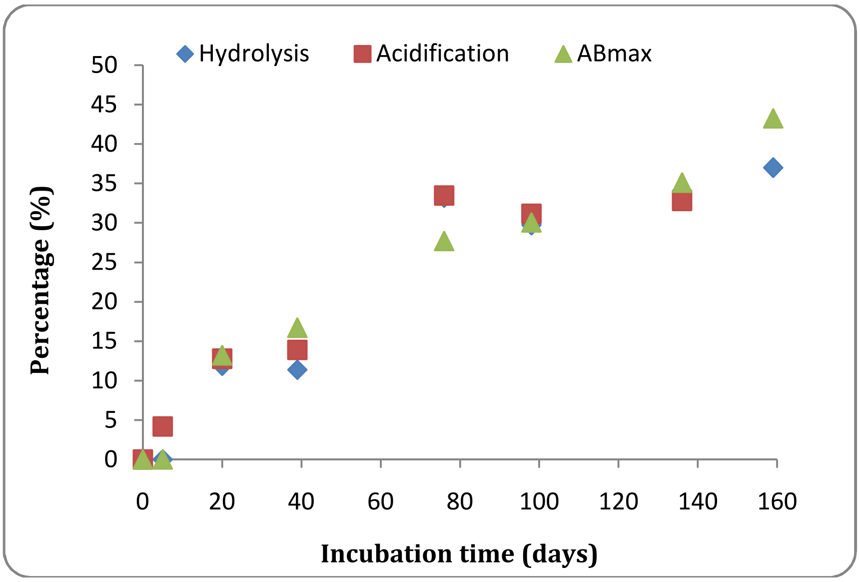

Figure 1: Hydrolysis, acidification and AB_{max} for unseeded single household wastewater at 25°C

AB_{max} of the single household wastewater was found to be 43% for unseeded samples (Figure 1) and 59% for seeded samples (Figure 2) after 159 days of digestion at 25°C. Obviously, samples' inoculation considerably affected anaerobic biodegradation. It could be possible that using more seed will result in better biodegradation. The measured biodegradability is lower compared with 76% reported for Abu-Nusier wastewater treatment plant influent after 130 days of digestion at 25°C (Halalsheh, 2002) and compared with raw sewage from other countries as shown in Table 4. It should also be noted that 86% of the biodegradable fraction was obtained after 27 days of unseeded incubation for the influent of Abu-Nussier wastewater treatment plant (Halalsheh, 2002), while this fraction was only 39% after 39 days of unseeded incubation for the single house wastewater.

Hydrolysis percentages achieved after 159 days of single house wastewater incubation, were 37% and 54% for the unseeded and seeded samples, respectively. Hydrolysis percentage achieved after 39 days of unseeded incubation was 11%. Provided that a hydrolysis percentage of 87% was achieved for the influent of Abu-Nussier wastewater treatment plant after 32 days of unseeded incubation (Halalsheh, 2002). The adoption of anaerobic systems for the single household wastewater treatment calls for special attention to overcome the prevailing limited hydrolytic activities. This can be realized by operating the anaerobic system under long SRTs (i.e., long HRT). Assuming first order kinetics, hydrolysis rate constant was calculated for the seeded and unseeded incubations at 0.006 d^{-1} (R^2= 0.877) and 0.004 d^{-1} (R^2=0.873), respectively. These rates can be considered low, especially if compared with hydrolysis rate achieved by Mahmoud (2002) for domestic wastewater settleable solids at 35°C, which amounted to $0.23d^{-1}$.

The prevailing low anaerobic biodegradability of the single house wastewater can be attributed to the excessive use of detergents. Several investigators reported poor anaerobic degradation of detergents (Nielsen, 2005; Mensah and Foster, 2003; Ferguson and Brownawell, 2003; Jimenez-Gonzalez et al., 2001). Moreover, anaerobic detergents, besides their poor anaerobic degradation, may inhibit the process of hydrolysis (Hernandez et al., 2001).

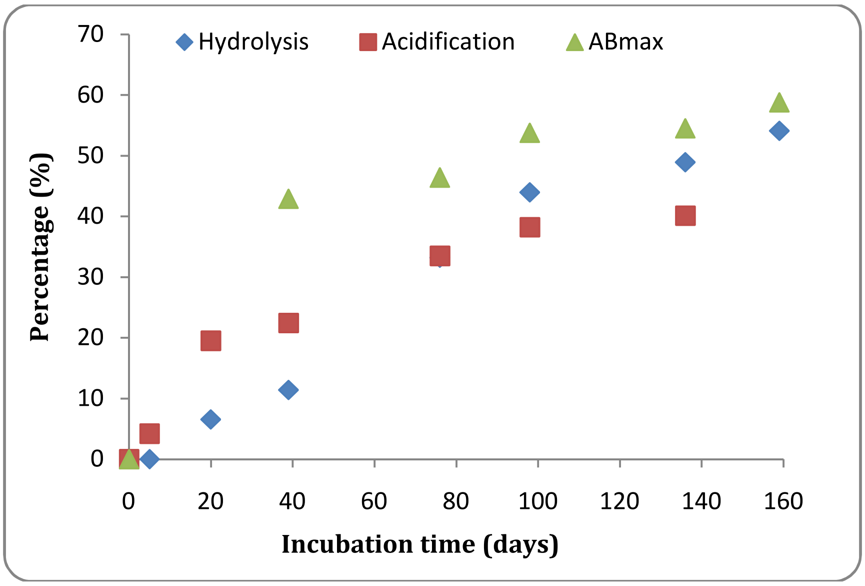

Figure 2: Hydrolysis, acidification and AB_{max} for seeded single household wastewater at 25°C

Additionally, the excessive application of disinfectants could be the reason for lower biodegradation of the single-house wastewater. Disinfectants limit the biological degradation and affect any treatment system that can be selected for house on-site treatment of such wastewater. Accordingly, it is highly recommended that households reduce the application of disinfectants and detergents, especially those unnecessarily used. Obviously, the initiation of awareness raising programs could be necessary for such purpose.

CONCLUSIONS

The household wastewater in Za'atri was characterized by high COD_{tot} with an average value of 2982 mg/l and 1683 mg/l for summer and winter, respectively. The suspended fraction of the COD represents only 41% and 38% for summer and winter, respectively.

Maximum anaerobic biodegradability of the household wastewater was limited to 43% and 59% for the unseeded and seeded samples, respectively. Moreover, hydrolysis percentages were limited to 37% and 54% for the unseeded and seeded samples, respectively.

The low anaerobic biodegradability was attributed to excessive use of detergents and disinfectants. Accordingly, the application of anaerobic system for treatment of this household wastewater is only feasible if consumption of detergents and disinfectants were substantially reduced.

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