Sustainable Treatment of Waste(water) in Rural Areas of Egypt

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Abstract

In this paper, a sustainable concept was proposed for decentralised treatment and reuse of sewage and cow manure in rural-areas of Egypt. Moreover, a mathematical model was developed for anaerobic digestion of the domestic sewage and cow manure in UASB-septic tank and accumulation (AC) system, respectively. For the treatment of sewage (600 mgCOD/l) in a UASB-septic tank at 20^oC, an HRT of 2 days is needed, which will lead to COD removal, biogas production rate and sludge wastage period of 65%, 14 litres CH_4/capita/day and 6 years, respectively. For the treatment of cow manure in an AC system at 20^oC, the required filling period is 6 months, which will result in conversion of 41% of the COD to methane at a rate of 0.2-1.2 m^3CH_4/cow/day. For a house having 7 capita and a cow, the annual volume of treated wastewater, sludge production and energy production, are, respectively, 307 m^3, 18.5 m^3 and 3428 kW.h, which can be utilised as irrigation water, fertiliser and cooking energy, respectively.

Keywords

anaerobic digestion, decentralised treatment, domestic sewage, cow manure, modelling, rural areas

Nomenclature

AC:	Accumulation system
COD:	Chemical oxygen demand (mg/l)
HFRF:	Horizontal-flow-roughing filter
HRT:	Hydraulic retention time (h)
K_d:	Decay of biomass (1/d)
K_{hyd}:	First-order hydrolysis constant (1/d)
K_s:	Half saturation concentration (mg COD/l)
SBS:	Small bore-sewer system
S_b:	Biodegradable soluble-substrate concentration (mg COD/l)
S_i:	Soluble-inert concentration (mg COD/l)
S_{ch4}	Converted Substrate to methane (mg COD/l)
UASB:	Upflow anaerobic sludge blanket
μ_{max}:	Maximum specific growth rate (1/d)
X_b:	Biodegradable-particulate concentration (mg COD/l)
X_i:	Inert-particulate concentration (mg COD/l)

X_m: Biomass concentration (mg COD/l)
Y: Yield of biomass on substrate (mg COD_S/mg COD_X)

Introduction

In Egypt, more than 90% of the Egyptian rural-areas are not provided with wastewater collection and treatment facilities. There are about 4000 Egyptian rural-areas with a population ranging from 1000 to 20000 capita. The wastewater produced from houses in these rural areas is mainly treated in septic tanks. To meet the demands for water and wastewater services in the next decade, Egypt will have to invest 5-7 billion US$, which is well above the available national resources (USAID, 2002). Providing rural areas in Egypt with water supply (more than 98% of rural areas in Egypt have water supply) has resulted in an increase of wastewater production, which increases the urgent need for proper facilities for wastewater collection and treatment. Elmitwalli *et al.* (2002a) showed that the domestic wastewater of the Egyptian rural-areas is relatively concentrated with a COD as high as 1100 mg/l, mainly due to the discharge of cow manure in the served areas with gravity sewers. This results in frequent clogging of the sewers and overloading of the existing wastewater treatment plant.

Separation between grey water and black water in rural areas of Egypt (for more sustainable collection, treatment and reuse) on the short term is very difficult, due to need for investment cost, existing infrastructures and poor education of Egyptian people in the rural areas. The aim of this paper is to develop an appropriate and sustainable concept for collection, treatment and reuse of domestic sewage and cow manure in rural areas of Egypt. Three concepts will be presented, depending on the local situation, like the population density and the existing infrastructures. Anaerobic digestion was chosen as the main process in this concept. Moreover, a simple mathematical model based on anaerobic digestion model no. 1 (IWA, 2002), is developed for determination the most suitable design of the proposed anaerobic systems.

Concept description

The concept is firstly based on separation of domestic sewage and cow manure. The separation of the cow manure from the wastewater will potentially reduce the pollution of the surface water, which represents the main source of drinking water in Egypt. The produced manure by 120 cows is equivalent to a total COD produced by about 10000 capita, based on the assumptions in Table1. In the concept, a UASB-septic tank and an accumulation (AC) system will be applied for treatment of, respectively, domestic sewage and cow manure. The UASB-septic tank differs from the conventional septic tank system by upflow mode, in which the system is operated resulting in both improved physical removal of suspended solids and improved biological conversion of dissolved components. In the AC system, anaerobic-digestion and storage of waste are combined in one reactor (Zeeman, 1991). For remote houses in Egyptian rural-areas, each house will have its own AC system and UASB-septic tank (Fig. 1.A), while for densely populated areas, several AC systems and UASB-septic tanks will be installed. An AC system and a UASB-septic tank will serve a small community in the densely-populated areas, like an AC system and a UASB-septic tank for each street. Shallow gravity sewers will collect the sewage from the houses to the UASB-septic tank (Fig.1.B). Also, in the densely populated areas, existing septic tanks can be easily modified to UASB-septic tanks. The tanks effluent, which contain low SS concentrations, will be collected by a small bore-sewer (SBS) system (low-cost technology for wastewater collection) to the nearby agricultural area (Fig. 1.C). Accordingly, the anaerobic effluent can be reused for irrigation after a polishing step, like a horizontal-flow-roughing filter (HFRF). The excess digested-sludge from the UASB-septic tanks and AC system, will be used as a fertiliser and the produced biogas will be utilised as a source of energy for food cooking, mainly making bread, like in the past, when the Egyptian people were burning dry cow manure for making bread.

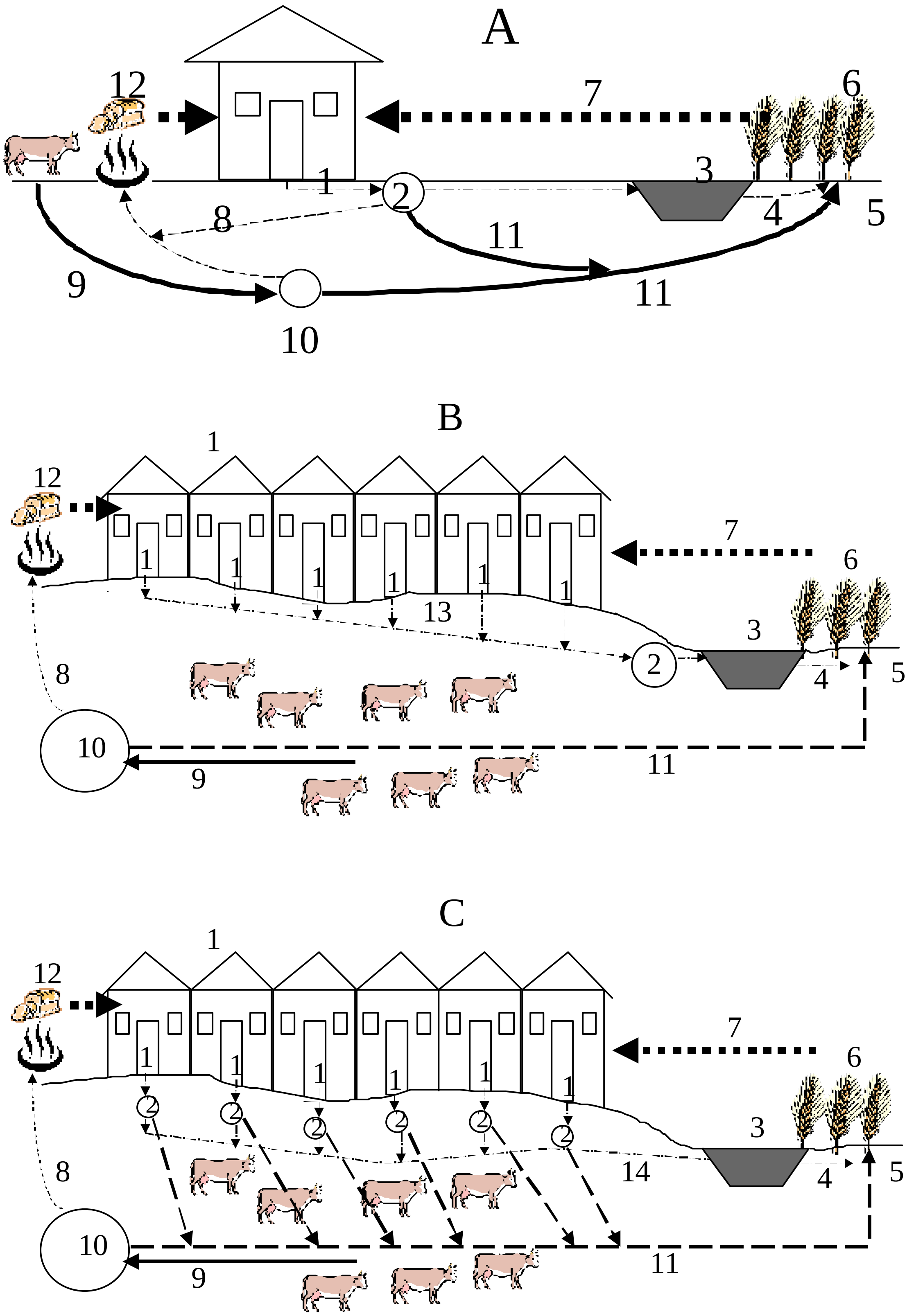


Figure 1: Schematic diagrams of the concept. (A) for a remote house, (B) for a densely-populated area, (C) for a densely-populated area with existing septic tanks. 1, domestic sewage; 2, UASB-septic tank; 3, HFRF; 4, treated sewage; 5, agricultural area; 6, plants; 7,

food; 8, biogas; 9, cow manure; 10, AC system; 11, digested sludge; 12, cooking by biogas; 13, shallow gravity-sewers; 14, SBS system.

Mathematical Modelling

The model is mainly based on first-order and Monod kinetics for, respectively, hydrolysis of biodegradable particulate and conversion of dissolved organic matter. Table 1 shows biochemical rate coefficients and kinetic rate equations for particulate and soluble components in the mathematical model and Table 2 presents the values of model constants and variables. The model was carried out using the QBASIC programme and applying numerical integration at small time interval of 7.2 and 1 minutes for UASB septic tank and AC system, respectively.

Table 1: Biochemical rate coefficients and kinetic rate equations for particulate and soluble components in the simplified mathematical model

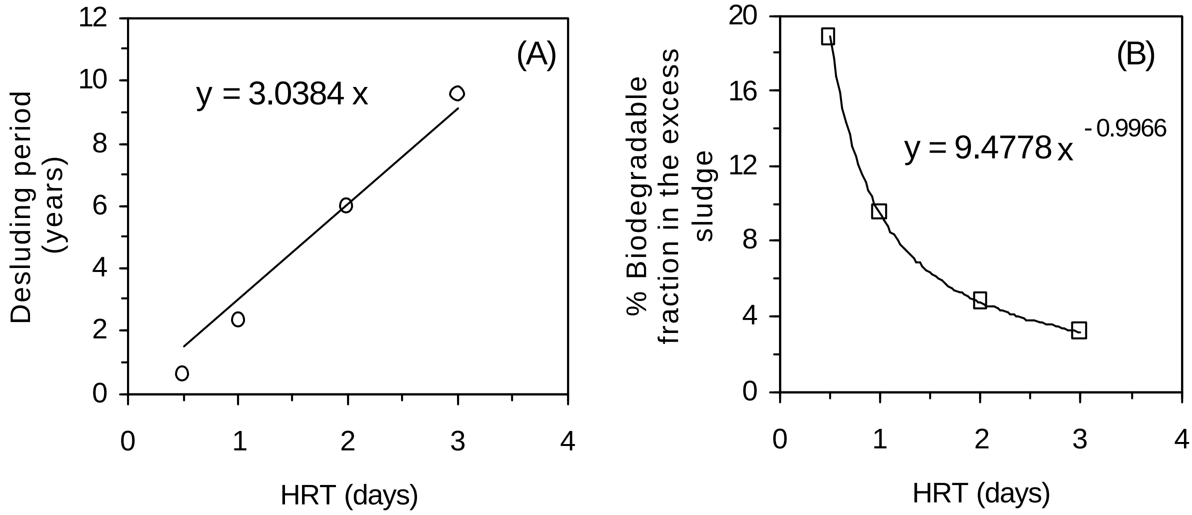
Component (i)→ Process (j) ↓	X_b	X_i	X_m	S_b	S_{CH4}	S_i	Rate
Hydrolysis	-1			1			$K_{hyd} * X_b$
Conversion			Y_m	-1	$1-Y_m$		$K_m * S_b * X_m / (K_s + S_b)$
Decay	1		-1				$K_d * X_m$

Table 2: Values of parameters and variables applied in the model.

Parameter						References
Concentration:-	X_b	X_i	X_m	S_b	S_i	
Domestic sewage, mg/l, (COD=600 mg/l, 120 l/capita/day)	365	18	37	117	63	Elmitwalli *et al.* (2001), Elmitwalli *et al.* (2002a)
Cow manure, g/l, (COD=120 g/l, 50 l/cow/day)	23.6	47.8	23.6	14.4	3.6	Zeeman (1991)
Kinetic parameters:-	Y	K_d	K_s	μ_{max}	K_{hyd}	IWA (2002)
Sewage (20°C)	0.1	0.02	400	0.15	0.15	
Cow manure (20°C)	0.1	0.02	400	0.15	0.03	
UASB-septic tank:- HRT = 0.5, 1, 2, 3 days, Sludge concentration = 35 g/l; Seed sludge = 25% of the volume, SS removal = 75%; Max. sludge volume = 70% of the reactor						Elmitwalli *et al.* (2002b), Elmitwalli *et al.* (2003)

Results and discussion

The model results show that increasing the HRT of the UASB septic tank from 0.5 to 3 days does not significantly affect the effluent COD and methane production, which were about 205 mg/l and 63% respectively. Such high performance is mainly due to long sludge residence time, which guarantees a sufficient biological activity and a stable physical performance. However,, increasing the HRT of the UASB-septic tank increases operational period of the reactor without sludge wastage (Fig. 2.A) and significantly decreases the biodegradable fraction in the excess sludge (Fig. 2.B). At HRT of 2 days, the reactor needs



to be desludged every 6 years. Accordingly, the HRT of 2 days can be considered sufficient for the treatment of domestic sewage in the UASB-septic tank.

Figure 2: Desludging period and biodegradable fraction in the excess sludge at different HRTs for a UASB septic-tank treating domestic sewage (600 mg COD/l) at 20^{o}C.

The model results for an AC system treating manure of a cow show that the performance of the system is significantly affected by the filling period, Fig. 3. Addition of inoculum in the start-up of the system slightly improves the performance (Fig. 3.B), as the influent has a sufficient amount of methanogenesis. Zeeman (1991) found that the cow manure could be treated in the AC system at 20^{o}C without inoculation. The results show that the suitable filling period for the system should be higher than 5 months. Therefore, the AC system can be operated for a period of 6 months, i.e. will be emptied twice a year. The results demonstrate that anaerobic digestion of cow manure in an AC system and treatment of sewage in a UASB-septic tank will produce, respectively, 0.2-1.2 m^3CH_4/cow/day and 0.014 m^3CH_4/person/day. Therefore, for treatment of cow manure and sewage of an Egyptian house in the rural areas (7 persons and a cow), the annual biogas production will be 370 m^3CH_4, which can produce theoretical energy of 3428 kW.h/year (can be used for cooking). Moreover, each house will produce about 307 m^3 of treated wastewater (can be reused for irrigation) and 18.5 m^3 of sludge (can utilised as a fertiliser).

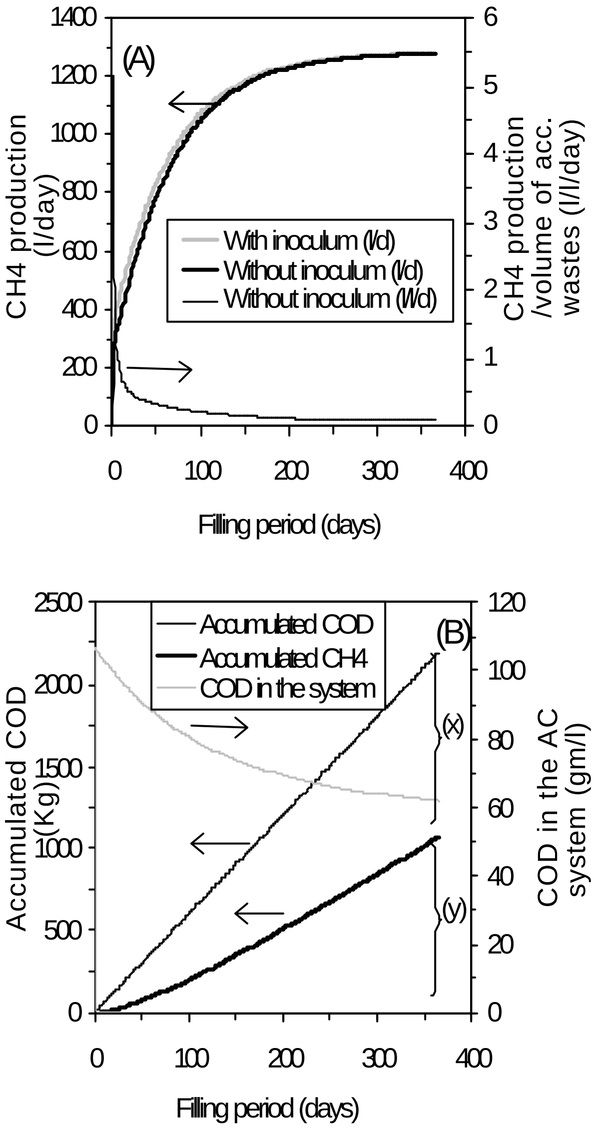


Figure 3: Daily CH_4 production (A) and accumulated total-COD and CH_4 production (B) in the digestion of manure of a cow in an AC system at 20°C. (x): non-degraded total-COD, (y): degraded total-COD. The inoculum = 10% of the AC system volume after a year.

Conclusions

- A sustainable concept was proposed in this paper for decentralised treatment and reuse of sewage and cow manure in the rural-areas of Egypt. Moreover, a mathematical model was developed for anaerobic digestion of the domestic sewage and cow manure in UASB-septic tank and accumulation (AC) system, respectively.

- The model results show that the suitable HRT and filling period for, respectively, the UASB-septic tank and AC system are 2 days and 6 months, respectively. At these conditions, 65% of COD in the sewage is removed with production of 14 litres of CH_4/capita/day and the excess sludge from the tank needs to be wasted every 6 years. In the AC system, 41 % of the COD in cow manure will be converted to methane at a rate of 0.2-1.2 m^3CH_4/cow/day.

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