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37th WEDC International Conference, Hanoi, Vietnam, 2014**SUSTAINABLE WATER AND SANITATION SERVICES
FOR ALL IN A FAST CHANGING WORLD****Co-treatment of organic fractions of urban waste for
energy recovery: a case study from Hanoi city, Vietnam***Duong Thu Hang, Vu Thi Minh Thanh, Nguyen Viet Anh, Vietnam***REFEREED PAPER 1971**

The authors have quantified material and energy flows in two options of co-treatment of organic fractions of wastes by composting, and by anaerobic digestion. The results shown thermophilic anaerobic co-digestion of septic tank sludge, sewage sludge and organic municipal solid waste has provided the biogas yield of 19.6 m³ per ton of mixed waste, equal to 114 kWh of heat and power. The calculation for the case of Long Bien district, Hanoi city has shown anaerobic co-digestion of waste fractions could generate 111,220 kWh of heat and power per day, helping the waste treatment complex to be self-sufficient in terms of energy. Besides, 32.2 MWh/day of surplus energy could be sold to the grid. This option also reduced emission of greenhouse gases versus composting. The study can be used as basis for cost-benefit analyses in selection of appropriate urban waste management options aiming at efficient utilization of engineering infrastructure systems, waste treatment and resource recovery.

Introduction

Rapid urbanization in many developing countries is creating pressures on engineering infrastructure system components, i.e. water supply, sanitation solid waste management well as energy supply. As many developing countries, while most of urban solid waste in Vietnam is still being disposed at landfills, there only one sixth of landfills are considered sanitary (VEA, 2012). Combined drainage and sewerage system is often applied in cities. Septic tank effluent and untreated gray wastewater are discharged to combined drainage and sewerage system, or go to the soil, open channels, etc. An average septic tank emptying interval is 4-6 years (Nguyen, 2011). Only 4% of urban septic sludge has been collected and treated properly (WB, 2014).

Currently about 10% of urban wastewater is being treated at 18 centralized wastewater treatment plants (WB, 2014). In coming years, a number of sewerage and drainage projects will continue to be implemented. While a major financial source for the project capital (Capex) is coming from foreign loans channelled via state budget, the operation and maintenance expenditures (Opex) should come from the users and budget of local authorities. To sustain sanitation system by ensuring Opex is a big challenge of cities in developing countries. Further, it is known that costs for energy cover the significant proportion in the Opex of wastewater, solid waste and sludge management systems. Composting of organic rich wastes has number of advantages. However, compost is still not a well-accepted technology in Vietnam and in number of other countries, due to presence of unsorted harmful materials, low quality of unsafe compost product, high energy consumption in compost production and transportation, etc. Compost of septic sludge and sewage sludge can hardly provide hygienically safe fertiliser.

Above mentioned challenges require search of new approaches. An anaerobic digestion of urban organic rich waste flows such as urban solid waste, sewage sludge, septic tank sludge for waste stabilization and biogas recovery is being proposed as one option. The results of project "Solutions for semi-centralized supply and disposal systems in urban areas - a case study in Hanoi, Vietnam (Semi-san)", implemented in cooperation of Technical University of Darmstadt and Hanoi University of Civil Engineering in 2009 – 2012 (Nguyen et al., 2013) have shown that urban solid waste from kitchens, restaurants, urban markets, etc. was rich of organic content or carbon (C), while septic tank sludge was rich of nutrients (N, P). Both wastes have

high ratio of bio-degradable fractions. Co-treatment of these two types of waste in anaerobic digester could provide optimum balance among nutrient elements, creating favour conditions in the digester for better decomposition of organics and generation of biogas. The Semi-san experiments at bench and pilot scales, batch and continuous modes on thermophilic anaerobic co-digestion of food waste and septic sludge have found the mixing ratio of COD sludge : COD waste 0.4:1, the organic loading rate of 1.5 kg COD/(m³·d) and the hydraulic loading rate of 30-40 L/d have provided maximum efficiency of methane production (76 %) and high methane percentage in biogas (65-70%) (Nguyen *et al.*, 2013). Generated methane is used as fuel for the combined heat and power system (CHP), supplying heat and power to operation processes at the waste treatment complex. The digested sludge from the thermophilic fermentation and drying meeting the Vietnamese standards for heavy metals and helminths can be used for soil enrichment in agriculture (Nguyen *et al.*, 2013). Several researches have pointed out that anaerobic digestion for stabilisation of sludge generated at wastewater treatment plants can produce biogas which can be used as fuel for thermal energy and power generation, and by this way part of energy demand in the wastewater treatment plants can be met, but the target of energy self-sufficiency hardly achievable (Lazarova *et al.*, 2012). Applying co-digestion of sewage sludge, septic sludge and other rich organic wastes can be a good solution to minimize amount of waste dumped in landfills, increase volume of methane generated, optimize the utilization of built urban engineering infrastructure components, and, hence, increase economic and environmental efficiency of the waste management system.

In order to find more concrete answers of this potentially applicable waste management approach, the authors have selected one urban district of Hanoi named Long Bien for a case study. The district has geographical boundary relatively separated from other districts, and can be representing as fast growing urban area.

Materials and methods

Current status of environmental sanitation in Long Bien district, Hanoi city

The current sewerage and drainage system in Long Bien district is the combined system. Most of households, offices and commercial buildings have septic tanks for primary treatment of wastewater. Overflow from septic tanks and untreated grey wastewater go to the combined sewerage and drainage network, from where wastewater is discharged to irrigation canals and rivers without further treatment. Septic sludge, when septic tanks are emptied, is dumped at landfills or illegally disposed to the environment. The leachate from dumping sites penetrates to the soil, or flows to the open water bodies. Besides a small proportion of generated solid waste (paper, plastic bags and metal cans) collected and recycled, the rest is dumped at landfills.

Proposal of waste treatment and management in Long Bien district

The organic composition in the domestic solid waste in Hanoi area was 55.74% (VEA, 2012). After separation, the organic fractions of waste can be treated by biological processes. Composting station of solid waste has been proposed for the Scenario 1. Septic sludge collected from septic tanks is transported and co-composted at the station. A combined sewerage and drainage system with with over-flow chambers has been proposed for the existing urban areas in Long Bien. In new development areas, a separate sewerage system has been selected. Wastewater from whole district catchment area is collected to a new wastewater treatment plant located at the south-east part of the district for both Scenarios 1 and 2. In the Scenario 2, integrated waste treatment complex of wastes is proposed at the wastewater treatment plant location. Generated sewage sludge is co-digested with collected septic sludge, and organic fractions of solid waste. Since at source separation of solid waste is not going to be realized soon in Vietnamese cities, a separation of organic from inorganic fractions of waste is proposed to be done at waste treatment complex. Inorganic part of solid waste is transported further for dumping at sanitary landfill. Figure 1(a) and Figure 1(b) illustrate waste flows in the two Scenarios. The Scenarios have been calculated for the year of 2020. The input data such as population, number of households, water flow, solid waste generation and collection ratio, etc. in Long Bien district is provided in Table 1. The quantity and characteristics of wastes were assumed to be similar in the two scenarios. Characteristics of septic tank sludge (Nguyen *et al.*, 2013), raw sewage sludge from primary clarifier and excess activated sludge from secondary clarifier, domestic solid waste (Shanmugam and Horan, 2008) was demonstrated in Table 2. It is assumed that septic tank management will be improved, and average frequency for septic tank emptying will be 3 years.

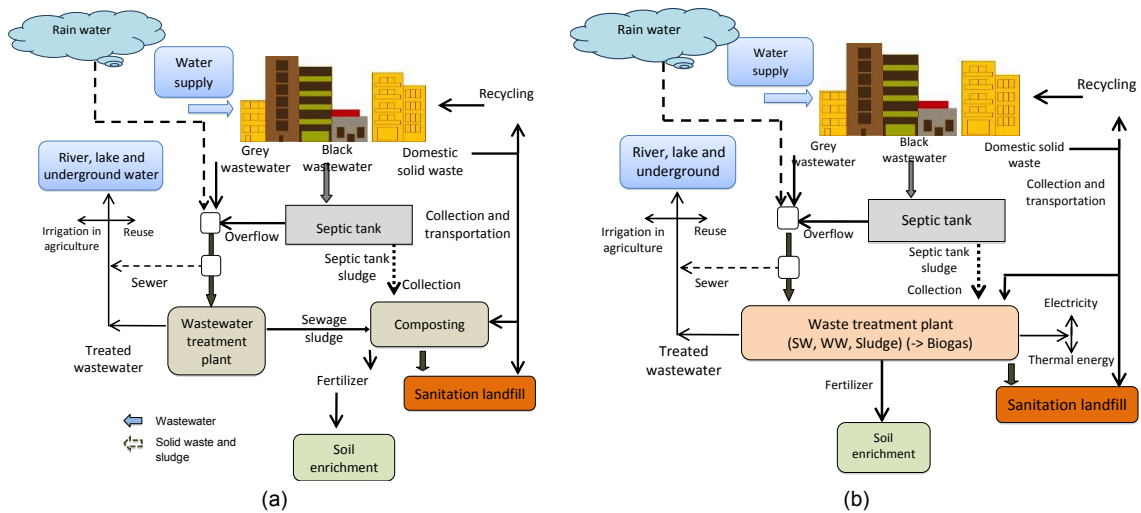


Figure 1. Diagrams of wastewater, solid waste and sludge management of in Scenario 1 (a) and Scenario 2 (b), Long Bien district, Hanoi

Population	Rate of birth	No. of people per household	No. of households
352,000 p.e.	1%	4.3	81,860
Total land area	Residential area	Commercial land area	Industry
6,038.02 ha	5,540.63 ha	155.86 ha	341.53 ha
Domestic WW flow	Commercial WW flow	Industrial WW flow	WW collection ratio
200 L/pe.day	25 m ³ /ha.day	45 m ³ /ha.day	80-100%
Domestic Solid waste flow	SW collection ratio	Average frequency of septic tank emptying	Volume of fecal sludge pumped out
1.2 kg/pe.day	100%	3 year/1 time	1.5 m ³ /time

Parameters	Septic tank sludge	Primary sludge	Activated sludge	Domestic solid waste
TS (%)	3.6	3.8	0.4	41.7
VS (%TS)	65	60.3	62.0	63.0
Chem. formulas	-	C ₁₄ H ₂₆ NO ₉	C ₈ H ₁₇ NO ₅	C ₂₅ H ₄₁ NO ₂₁
C:N	4.3	14.0	6.7	21.6
NH ₃ -N (mg/L)	97	305	466	414
Alkalinity (mg/L)	-	5,703	7,997	6,821

In the Composting plant (Scenario 1), the organic compounds in the sludge and solid waste are aerobically degraded and converted into organic fertilizer (compost). The volume of waste is reduced but energy is not generated. The mass balance of composting process was based on the study of Hampejs (2010) analysing 16 mechanical and biological waste treatment plants in Austria. Estimated energy requirements for operation of the composting facilities are shown in Table 3 (Komilis and Robert K. Ham, 2000).

Equipment	Number of units per (ton * day)	Energy requirement
Trommel screens ^c	0.0025	1.07 - 1.47 HP*h/ton (pre-composting)
Hammer mill ^c	0.0029	20 HP*h/ton*(CF)*1.64 ^c
Tub grinder ^d	0.0038	13.7 HP*pad/ton
Windrow turner ^d	0.173 ^a	0.173 HP/(ton * hour)
Front-end loader ^d	0.003	0.5 HP/(ton per day) ^c

- a: Coefficient based on the number of tons of compost present at the composting pad multiplied by the turning frequency;
- b: Values of 1.00 and 0.65 were used for raw and pre-sorted municipal solid wastes, respectively;
- c: Based on regression as discussed in text, assuming capacity of one unit is 150 HP;
- d: Diesel powered motor;
- e: Electricity powered motor.

In the scenario 2, energy demand (input) of the thermophilic anaerobic digestion system was for pumping, grinding, stirring, demonstrated in equations from (1) to (5). Heat exchanger was used to utilize heat of the outflow sludge for increase of the temperature of the inlet sludge (Metcalf and Eddy, 1991; Ferrer et al., 2008; Lu et al., 2008; Astals et al., 2012).

$$E_{input} = E_{electricity\ in} + E_{sludge\ heat} \quad (1)$$

$$E_{electricity\ in} = E_{pumping} + E_{stirring} \quad (2)$$

$$E_{pumping} = Q \cdot \theta \left(\frac{kJ}{day} \right) \quad (3)$$

$$E_{stirring} = V \cdot \omega \left(\frac{kJ}{day} \right) \quad (4)$$

$$E_{sludge\ heat} = Q \cdot \rho \cdot \gamma \cdot (T_d - T_{SS}) \cdot (1 - \varphi) \cdot (1 + \epsilon) \left(\frac{kJ}{day} \right) \quad (5)$$

Energy generation (output) was the amount produced from the anaerobic fermentation system including both heat and electricity of CHP from burning biogas, was calculated in equation (6) and (7). In sum, the energy (E) produced from the system was expressed in equation (8).

$$E_{output} = E_{electricity\ CHP} + E_{heat\ CHP} \left(\frac{kJ}{day} \right) \quad (6)$$

$$E_{output\ t} = P_B \cdot V \cdot \alpha \cdot \pi + P_B \cdot V \cdot \alpha \cdot \beta \quad (7)$$

$$E = E_{output} - E_{input} \left(\frac{kJ}{day} \right) \quad (8)$$

In which:

- Q : Flow of the inlet sludge flow, m^3/day ; θ : Electricity for pumping, $1,8 \cdot 10^3\ kJ/m^3$ (Lu et al., 2008);
- V : Working volume of the digesters, m^3 ; ω : Electricity for stirring, $3 \cdot 10^2\ kJ/m^3\ unit\ of\ digester/day$ (Lu et al., 2008);
- ρ : Specific weight of sludge, approximately $1,000\ kg/m^3$ (Metcalf and Eddy, 1991);
- γ : Specific heat capacity of sludge, $4,18\ kJ/kg \cdot ^\circ C$ (Metcalf and Eddy, 1991);
- T_d : Temperature of digester, $55\ ^\circ C$;
- T_{SS} : Temperature of the inlet sludge, $^\circ C$;
- φ : Heat recovery ratio from the outflow and the inflow through heat exchanger, $0,85$ (Lu et al., 2008);
- ϵ : Heat loss ratio, $0,08$ (Lu et al., 2008);
- P_B : Biogas yield, $m^3\ biogas / m^3\ digester/day$;
- α : Heat energy of biogas, $23,270\ kJ / m^3\ biogas$ (Metcalf and Eddy, 1991);
- π : Efficiency of electrical generation of CHP, approximately $0,35$ (Astals et al., 2012);
- β : Efficiency of thermal generation of CHP, approximately $0,55$ (Astals et al., 2012);

Results and discussions

Mass balance calculations and energy analysis

Figures 2 (a) and 2 (b) show the results of mass balance calculation for the composting system in the Scenario 1, and the thermophilic anaerobic digestion system in the Scenario 2, respectively.

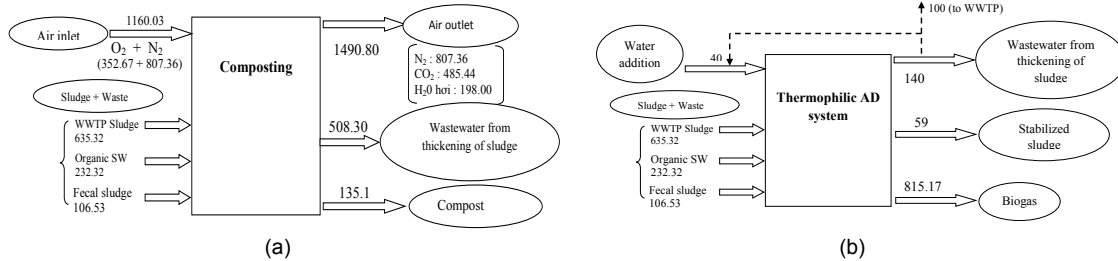


Figure 2. Diagram from mass balance calculations for the Composting plant (a) and the Anaerobic digestion plant (b) (unit: ton/day)

The energy consumption and energy generation (heat and electricity) in the two systems, composting and anaerobic digestion, in two scenarios respectively, are shown in Table 4. Co-composting of sludge and organic solid waste requires energy consumption of 11.4 KWh per ton of waste treated. This value is

comparable to other studies where energy requirement for composting plant processes of mixing, rolling and windrowing was ranging from 11 to 17 KWh per ton of waste treated (Tchobanoglous et al., 1993). With the total amount of waste and sludge generated in Long Bien district, the energy consumption was 11,058 KWh per day. The amount of biogas produced from anaerobic digesters was 19.6 m³ per fed ton of waste and sludge. Total electricity-heat energy gained from the CHP was 114 KWh per ton of waste and sludge, or 111,220 KWh per day calculated for the entire district, while power consumption demand for anaerobic digestion system was 19.5 KWh per ton of waste or 18,957 KWh per day. The remaining surplus energy obtained was 94.7 KWh per ton of waste or 92,263 KWh per day. This amount even has exceeded the total need of energy for the whole waste treatment complex, which was as much as 0.8 KWh per m³ per day, or 60,080 KWh per day. The surplus energy of 32,183 KWh/day after self-sufficient supply to the waste treatment complex can be sent to the city's grid. In addition, 0.06 tons of safe fertilizer per fed ton of waste, or 59 tons of organic fertilizer per day was produced.

Table 4. Energy analysis for the two scenarios			
No.	Treatment projects	Loading (ton/day)	Equivalent energy (KWh/day)
1	<i>Scenario 1, composting</i>		
A	Energy consumption	974.17	11,058
2	<i>Scenario 2, anaerobic digestion</i>		
A	Energy consumption	974.17	18,957
B	Electricity generation from CHP		43,252
C	Heat generation from CHP		67,967
D	Total energy generation from CHP		111,220
E	Surplus energy from AD system		92,263
F	Energy consumption for the WWTP	75,000	60,080
G	Surplus energy in the treatment of waste		32,183

In order to recover nutrients and energy, municipal solid waste, sewage sludge and septic tank sludge were proposed to be biologically co-treated in both scenarios. The area required for landfills was minimized, while the risk of public health and environmental pollution at dumping sites was certainly reduced. The anaerobic co-digestion of urban organic waste at thermophilic condition has several advantages compared with the aerobic composting of waste as follows: (i) Anaerobic fermentation process uses CO₂ available in the system as an electron acceptor. Completely no use of oxygen saves energy for air supply for composting, hence, the operation cost remarkably decreases. (ii) in terms of biochemical metabolism of organic matters in substrates, anaerobic fermentation of organics generates an amount of biomass 3-20 times less than aerobic process does (Chernicharo, 2007). (iii) most of the energy released from the organic compounds is converted into the final product of the anaerobic fermentation, biogas, which contains 65-70% of CH₄. Methane is a source of "green" energy which contains about 9,000 Kcal per m³ of gas. It can be burned for supply of thermal energy to the waste treatment processes, i.e. heating up of the reactors, drying of digested sludge, or sent to the generator for producing of electricity. The final products in aerobic decomposition process mainly compose of CO₂, which has no value, escaping into the atmosphere as greenhouse gas emissions.

In the study on application of anaerobic digestion technology in European solid waste treatment plants, Nguyen (2004) pointed out that energy demand for degradation of rich organic waste in anaerobic digesters was 2-15 KWh higher than in composting. Full-scale applications in Brecht, Salzburg (Austria) and Bassum (Germany) generated the biogas respectively 165, 220 and 245 KWh per ton of waste processed. Thus, in terms of energy balance, 150-230 KWh was produced and transformed into electro-thermal energy from each ton of rich organic waste. According to Biey et al. (2003), the investment cost of anaerobic digestion plants was 1.2-1.5 times higher than that of composting plants, but thanks to this fermentation process, about 10-150 m³ of biogas was generated from each ton of organic-rich waste. The richer the organic content of waste is or by co-digestion of sludge and rich organic waste, for example food industry waste and agricultural residuals, the more its economic and environmental benefits are intensified.

Conclusions and recommendations

The analysis and comparison between two scenarios of waste management in the case of Long Bien district, Hanoi city have shown that, the application of anaerobic digestion of different kinds of waste, i.e. septage, sewage sludge and municipal organic waste at high temperature (thermophilic conditions) has number of advantages, especially in terms of energy efficiency. After being sorted out at the treatment complex, the inorganic fractions from urban waste are transported to landfills if they could not be recycled. The organic fractions are anaerobically co-digested with septage, sewage sludge to produce biogas. The digested sludge in the process has been completely stabilized and thus it could be used as soil enrichment, or dried and then burned to generate again energy. The liquid phase from digester can be used for control of water content in the feeding materials, or further treated for final disposal or reuse. This solution can help to recover from each ton of the fed mixed waste 19.6 m³ of biogas which equivalent to 114 kWh of heat and power energy. An electricity-heat energy of 111,220 kWh per day could be generated from a total of 422.4 ton of municipal solid waste, 106.5 ton of septic sludge, and 635.3 ton of sewage sludge in Long Bien district. The recovered energy is self-sufficient for the whole waste treatment complex, including wastewater, sludge and solid waste treatment need, and also provides approximately an amount of electrical-thermal surplus energy of 32.2 MWh per day to the city. This idea of integrate waste management and treatment opens up an opportunity for other types of rich organic waste such as waste from food industry, agricultural activities. Anaerobic fermentation technology also helps to minimize greenhouse gas emissions compared to the composting process.

The urban development planning will have to adjust to accordance with the development of population growth and to consider impacts of climate change. This is a great opportunity to apply more sustainable approaches and new technologies in waste management. Planning of integrated waste management system at appropriate scales would allow finding of available money and land, to increase technical and financial feasibility of the project, while resources are more effectively recovered.

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