ANAEROBIC DIGESTION OF SLUDGE IN WASTEWATER TREATMENT PLANT FOR ENERGY RECOVERY – A CASE STUDY OF HANOI URBAN DISTRICT

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ABSTRACTS

In a wastewater treatment plant (WWTP) energy optimization is a big concern whilst sludge stabilization and energy recovery by anaerobic digestion implementation has recently gained importance. The calculation of an urban district level (selected as Long Bien) with 352,000 populations showed that with a total energy required of 39,750 kWh per day in WWTP, it could be supplied by utilization of biogas production, varying from 0% to ~ 43.44 % depending upon the non-application or application of anaerobic digestion for sludge treatment. In mesophylic anaerobic digestion, the biogas yields production of the calculated WWTP was obtained at 3,710 m^3/day; equal to 8,394 kWh power and 13,919 kWh heat per day. As a conventional treatment process, centrifugal dewatering of sludge required an additional energy of 1,376 kWh per day for recycling, pumping, mixing as well as transporting sludge. The conclusion was that anaerobic digestion can reduce the green-house gases versus conventional dewatering. The results from this research can thus demonstrate the applicability of anaerobic digestion on conversion of waste to energy, looking forward to resource recovery.

Keywords: Anaerobic digestion; biogas; energy; sewerage sludge treatment; resource recovery.

1. INTRODUCTION

Energy consumption in a wastewater treatment plants is depended upon various factors (i.e. the size, design and operation of the plant; the characteristics of wastewater; and other local aspects); but it is generally estimate to add up 108,000 – 216,000 kJ/person per year [1].Recently, municipal wastewater is being looked at more as a renewable resource than as a waste, that can recover energy [2]. The optimization of energy has been commonly implemented in developed regions. In this respect, anaerobic digestion has shown its efficacy on conversion of waste to energy [3]. Several researches have pointed out that anaerobic digestion for stabilization 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 [4]. In Vietnam, less than 10 % of urban wastewater (in 2011) is centrally treated and sludge is currently treated by conventional treatment (i.e. dewatering or composting), requiring high energy consumption [5]. Applying anaerobic digestion of sewage sludge can be a potential solution to minimize amount of waste dumped in landfills, increase biogas production, optimize the utilization of built urban engineering infrastructure components, and, hence, increase economic and environmental efficiency of the waste management system. In perspective of potentially applicable waste management approach, Long Bien – a Hanoi urban district has been selected as a case study. The investigation site has geographical boundary relatively separated from other districts, and can be represented as fast growing urban area.

2. MATERIALS AND METHODS

2.1. Study site description and proposed sludge management solutions as scenarios

In this research, Long Bien – an urban district of Hanoi was investigated for a sludge (in WWTP) management solution. The investigation site has a total area of 6,038.24 ha with approximately of 325,000 populations. The landuse is forecasted of upto 157.87 ha for public or service purposes and approximately of 341.53 ha for industrial zones, handicraft villages, and reserve lands [6]. The current sewerage and drainage system in Long Bien district is the combined system. Assume that about 80 % of urban wastewater and 100 % industrial wastewater are collected; capacity of WWTP in Long Bien district would be calculated as 75,000 m^3/day, resulting in about 630.35 tons/day of sludge production.

As addressed as a flexible technology, semi-centralized system which would reduce the density and the size of pipe network, demonstrating the efficacy on economic benefits, resources reuse and energy recovery and it also allows managing wastewater and sludge in both small and large scales [6]. Due to these advantages, a semi-decentralized wastewater treatment is proposed for wastewater treatment solution of the case study. Wastewater is being treated via several facilities such as a reservoir, screening, vertical sand separator, settling tank and sequence batch reactor. Two scenarios were proposed for sludge treatment (i.e. anaerobic digestion – scenario 1 and centrifugal dewatering – scenarios 2). In scenario 1, the sludge is stored before being digested in mesophylic anaerobic reactor; and in scenario 2, the sludge would be dewatered by centrifuge; after that would be dumped the landfill.

2.2. STAN application for the mass balance calculation

STAN (subSTance flow Analysis**)** software was applied to modelmass balance and energy analysis of the case study. This tool performs material flow analysis according to the Austrian standard ÖNorm S 2096 (Material flow analysis - Application in waste management) [7]. After building a graphical model with predefined components (i.e. processes, flows, system boundary, text fields), the known data (i.e. mass flows, stocks, concentrations, transfer coefficients) for different layers (i.e. mass, energy) and periods would be entered or/ and imported to calculate unknown quantities.

2.3. Energy calculations

2.3.1. In mesophylic anaerobic digestion system

In scenario 1, energy demand (E_{input}) of the mesophylic 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 temperature increasing of the inlet sludge [8, 9, 10, 11].

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

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

$$E_{pumping} = Q.\theta \quad (3)$$

$$E_{stirring} = V.\omega \quad (4)$$

$$E_{sludge\ heat} = Q.\rho.\gamma.(T_d - T_{SS}).(1 - \varphi).(1 + \epsilon) \quad (5)$$

Energy generation (output) was the amount produced from the anaerobic fermentation system including both heat and electricity of Combined Heat and Power (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).

$$E_{output} = E_{electricity\ CHP} + E_{heat}\ CHP \quad (6)$$

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

$$E_{surplus} = E_{output} + E_{input} \quad (8)$$

The meanings and values of the symbols in equations from (1) to (8) are indicated in Table 1.

*Table 1.*Meanings and values of coefficients for energy calculation.

Symbols	Meaning	Values	Source
E_i	Energy consumption for process of i, kJ/day	-	*To be calculated*
Q	Flow of the inlet sludge flow, m^3/day	630.65	*Calculated*
θ	Electricity for pumping, kJ/m^3 unit of tank/day	1.8 x 10^3	*Lu et al., 2008*
V	Working volume of the digesters, m^3	9460	*Calculated*
ω	Electricity for stirring, kJ/m^3	3.10^2	*Lu et al., 2008*
ρ	Specific weight of sludge, kg/m^3	1000	*Metcalf and Eddy, 1991*
γ	Specific heat capacity of sludge, kJ/kg.^{o}C	4.18	*Metcalf and Eddy, 1991*
T_d	Temperature of digester, ^{o}C	20	*Assumed*
T_{SS}	Temperature of the inlet sludge, ^{o}C	37	*Mesophylic condition*
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	3,710	*Calculated*
α	Heat energy of biogas, kJ/ m^3 biogas	23270	*Metcalf and Eddy, 1991*
π	Efficiency of electrical generation of CHP	0.35	*Astal et al., 2012*
β	Efficiency of thermal generation of CHP	0.55	*Astal et al., 2012*

2.3.2. In dewatering process

In scenario 2, energy consumption which was for the sludge processes as pumping, stirring, circulating and transporting, was calculated and provided in Table 2.

Table 2. .The calculation of energy requirement in scenario 2

Parameters	Equations	Values	Source
Energy demand for process of i	$E_{pumping} = \Sigma$ Q.θ, kJ/day $E_{stirring} = \Sigma$ V.ω, kJ/day	-	*See in equation (3) and (4)*
Energy demand for reclycling	E re =3600*(e-re *Σm-w)/ρ, kJ/day e-re is electricity for recycling, W/m^3 m-w is recycled water mass, tons/day	- 15 565.14	 *ATV-DVWK 368* *Calculated*
Energy demand for transporting	E_{trans} =3600* (e_{diesel} * m_{cen})/ρ, kJ/day e_{diesel} is energy of diesel engine, kWh/tons m_{cen} is dewatered sludge mass, tons/day	- 0.4 188.03	 *Metcaft & Eddy, 1991* *Calculated*
Energy demand	E = ($E_{pumping}$+$E_{stirring}$ +E_{re} + E_{trans})/3600, kWh/day	-	*To be calculated*

3. RESULTS AND DISCUSSIONS

3.1. Mass balance calculation

Figures 1a and 1b show the results of mass balance calculation for the mesophylic anaerobic digestion system in scenario 1 and centrifugal dewatering system in scenario 2, respectively. The results shown the mass flows analysis of two systems based on the performance of STAN software.

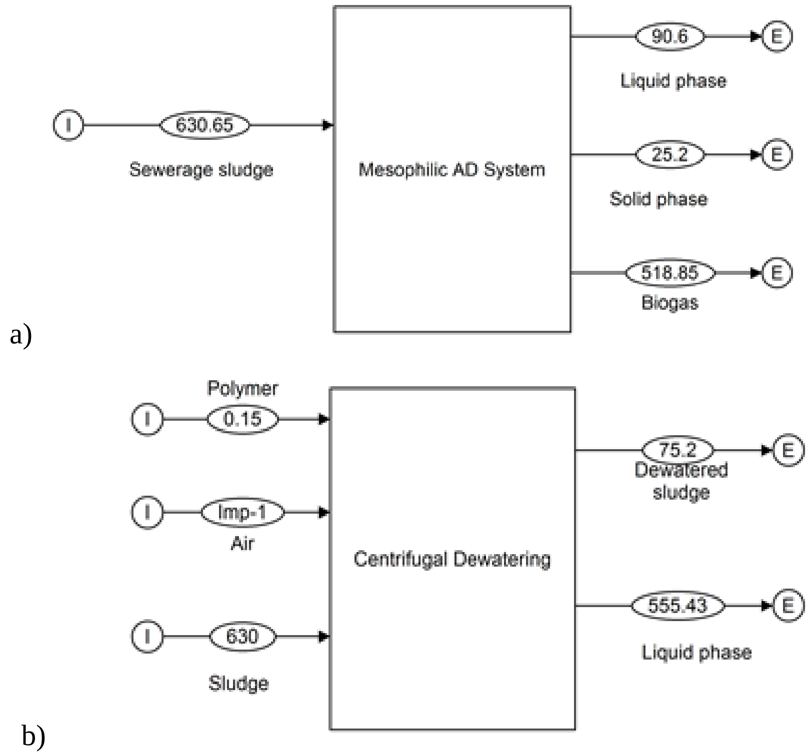

Figure 1. Diagram from mass balance calculations with I is imput flow and E is output flow for a)Anaerobic digestion systemand and b) Centrifugal dewatering system (unit: tons/day).

Biogas production from anaerobic digestion (scenario 1) was about 3,710 m^3/day; in addition, 25.2 tons of solids and 90.6 tons of liquid per day was produced (as seen in Figure 2 a). In centrifugal dewatering process, it was required to supplement about 0.15 tons of polymers and 37.64 m^3 of air per day in order to treat 630.65 tons of sludge per day; resulting in 75.2 tons of dewatered sludge per day and releasing 555.43 tons of liquid per day. In anaerobic digestion, less dried sludge and less amount of liquid were produced than in centrifugal dewatering. Moreover, anaerobic digestion is a good application for energy recovery due to biogas production.

3.2. Energy analysis

The energy consumption and energy generation (heat and electricity) in the two scenarios are shown in Table 3.

Table 3. Energy analysis for the two scenarios

Parameters	Anaerobic digestion	Centrifugal dewatering
Sludge loading (tons/day)	630.65	630.65
Energy demand (kWh/day)	4318	1309
Electricity generation from CHP (kWh/day)	8394	-
Heat generation from CHP (kWh/day)	13191	-
Total energy generation from CHP (kWh/day)	21585	-
Surplus energy from AD system (kWh/day)	17267	-
Energy demand for WWTP (kWh/day)	39750	39750
Energy demand for heat drying (kWh/day)	1031	-
Energy demand for water circulation (kWh/day)	1359	-
Energy balance in treatment plant	-23515	-41051
Energy recovery fraction (%)	43.44	0

With a biogas production as 3,710 m^3/day (in Table 1) from treatment of 630.65 tons of sewerage sludge per day, energy generation from CHP was gained as 21,585 kWh/day, with 8,394 kWh power and 13,919 kWh heat per day, versus; in contrast about 1,708 kWh/day of power consumption was required for anaerobic digestion system. The remaining surplus energy was therefore obtained of 17,267 kWh/day. The energy consumption for heat drying of the digested sludge was 1,031 kWh/day and for water recycling was 1,359 kWh/day. Since the total energy require for WWTP (capacity of 75,000 m^3/day) was 39,750 kWh/day; thus, about 43.44 % of energy was recovered for the whole treatment complex (for both wastewater and sludge). It is good potential for sufficient or more energy recovery via anaerobic co-digestion of solid waste and sludge; and the residual energy can be sold or utilized for other purposes.

Centrifugal dewatering of sewerage sludge requires energy consumption of 1,309 kWh/day, increasing energy requirement in waste treatment complex up to 41,051 kWh/day. Due to non-energy generation, non-recovery fraction of energy was obtained in this treatment process (provided in Table 3). The results hence demonstrate the benefits of mesophilic anaerobic digestion, compares to centrifugal dewatering in wastewater sludge treatment.

4. CONCLUSIONS AND RECOMMENDATIONS

The analysis and comparison between two scenarios of sewerage sludge management in the case of Long Bien district, Hanoi city have shown the benefits in energy aspect of mesophylic anaerobic digestion by producing a large amount of biogas. The digested sludge in the process has been post-treated for soil application or/and energy generation. The liquid phase from digester can be further treated for final disposal or reuse. The recovered energy in this solution can self-supply about 43.44 % of total energy require for the whole waste treatment complex, including wastewater, sludge and solid waste treatment need.

In order to ensure self-sufficient energy for the treatment complex from recovered energy, the authors recommend to 1) co-treatment of sewage sludge with other wastes for enhancement of biogas production; 2) pre-treatment of sludge before anaerobic digestion. The idea of integrated waste management and treatment would open up an opportunity for other types of rich organic waste such as waste from food industry, agricultural activities.

REFERENCES

1. Kolisch G., Osthoff T., Hobus I., Hansen J. - Experiences of Energy Analyses carried out in Germany, In: Proceedings of the 1st IWA water & energy conference: mitigation in the water sector & potential synergies with the energy sector, Copenhagen, Denmark, 2009.
2. McCarty P. L., Bae J., Kim J. - Domestic wastewater treatment as a net energy producer – can this be achieved? Environ. Sci. Technol. **45** (2011) 7100–7106.
3. De Baere, L., Mattheeuws B. - Anaerobic digestion of the organic fraction ofmunicipal solid waste in Europe – status, experience and prospects, Waste Management: Recycling and Recovery **3** (2012) 517–526.
4. Lazarova V., Peregrina C. - Towards energy self-sufficiency of wastewater treatment: Water and Energy interactions in water reuse. IWA publishing: 87-126.
5. ADB (2015). Vietnam urban environment program: Urban sanitation issues in Vietnam, Publication Stock No. ARM157646-2, 2012.
6. Nguyen, V. A., Duong T. H., Vu T. M. T. - Co-treatment of organic fractions of urban waste for energy recovery - a case study from Hanoi city, Vietnam. Proceedings in the 37th WEDC International Conference, Hanoi, Vietnam, 2014.
7. TU Vienna, Institute for Water Quality, Resource and Waste Management, STAN2web. (2012), http://www.stan2web.net/infos/about-stan
8. Metcalf and I. Eddy - Wastewater engineering, Treatment, Disposal and Reuse. United States of America, McGraw-Hill, Inc., 1991.
9. Ferrer, I., S. Ponsa, F. Vazquez and X. Font - Increasing biogas production by thermal (70 degrees C) sludge pre-treatment prior to thermophilic anaerobic digestion, Biochemical Engineering Journal **42** (2) (2008) 186-192.
10. Lu J., H. N. Gavala, I. V. Skiadas, Z. Mladenovska, and B. K. Ahring - Improving anaerobic sewage sludge digestion by implementation of a hyper-thermophilic pre-hydrolysis step, Journal of Environmental Management **88** (4) (2008) 881-889.
11. Astals S., C. Venegas, M. Peces, J. Jofre, F. Lucena, and J. Mata-Alvarez - Balancing hygienization and anaerobic digestion of raw sewage sludge, Water Research (www.elsevier.com/locate/watres) **46** (2012) 6218-6227.