MODELING AND COST ESTIMATION OF ENERGY PRODUCTION FROM SLUDGE

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ABSTRACT

Energy recovery from sewage sludge offers an opportunity for sustainable management of sewage sludge and energy. Anaerobic digestion and pyrolysis are among the most promising processes applicable for sewage sludge-to-energy conversion. Anaerobic digestion of sewage sludge forms methane-rich biogas, which can be utilized as fuel to offset heat and electricity consumption of the wastewater treatment sector. However, the digestion process has the efficiency limitation since it cannot sufficiently extract the energy from sewage sludge. The digested sludge is still energy profitable and it contains considerable organic matter, but poor in biodegradability. This paper presents a brief overview of anaerobic digestion, pyrolysis, and the combination of other processes with anaerobic digestion in the application to bio energy production from sewage sludge. An assessment of energy conversion of five sludge to energy pathways is also presented. The pathways via pyrolysis and the combination of anaerobic digestion, thermal hydrolysis, and thermal drying could achieve higher energy efficiency compared to other pathways.

KEYWORDS

Biofuel production; cost effective process; energy efficiency; sludge management; wastewater treatment

1 INTRODUCTION

Sewage sludge has been used as a fertilizer in many areas all over the world; however, it can also contribute in solving a number of problems of energy supply and healthy advantage of being a renewable energy source [1]. The production rate of sewage sludge is significant, for instance, nearly 1 million m^3/year of sewage sludge dry solids are produced in the UK [1], 4.2 million m^3/year in Switzerland, and 50 million m^3/year in Germany. Therefore, this massive energy source could be utilized by different technologies. Some of them have been used to extract energy from sewage sludge, including anaerobic digestion, pyrolysis, gasification, and hydrothermal carbonization. Although anaerobic digestion (AD) is thought of as one of the most technically mature and cost effective processes to convert sludge to methane-rich biogas,

the digested sludge as a byproduct of the process still has energy content which could be harnessed by several procedures such as pyrolysis and thermal drying. The objective of this paper is to present several processes to estimate the energy recovery and compare the results. A comparison between several processes has been made and these are listed below:

1. Conventional AD and land recycling of the digestate to agriculture [2].
2. Thermal hydrolysis process (THP), AD, and land recycling of the digestate to agriculture [2].
3. THP, AD, and sludge drying for fuel [2].
4. TH pretreatment and sludge drying for fuel [3].
5. Pyrolysis [4].

Application of THP improves the financial and environmental performance compared with conventional AD. The AD process with drying options and pyrolysis which were used to create a solid fuel were the most sustainable solution economically and environmentally. This study compared economic and environmental effects of these five technology configurations.

2 ANAEROBIC DIGESTION

Currently the most widely used method of sludge treatment is AD which could be divided into three different temperature ranges, known as psychrophilic (ambient temperature), mesophilic (30-38°C) and thermophilic (50-57°C) [5]. The mesophilic process consistently remains dominant in practical application, principally because of its combined benefits with acceptable energy consumption, reliable process operation and favorable process performance (e.g. sludge reduction and bio-gas generation) [6, 7]. In a typical process, sludge is thickened then heated to 35-40°C before entering the mixed digester tank, the retention times range from 12 to 30 days. The final digested is then dewatered to a cake and transported off site, for recycling on agricultural land [8]. Figure 1 shows the energy flow for a typical AD configuration.
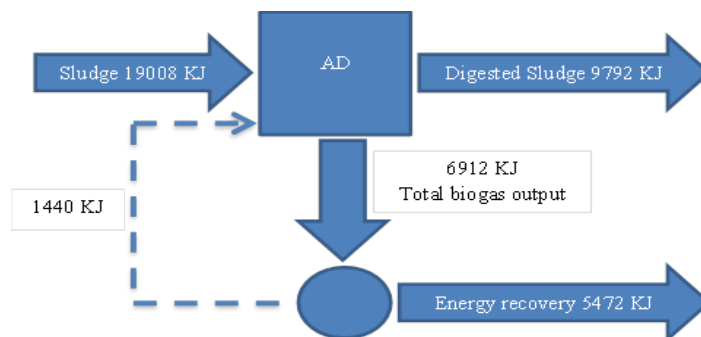

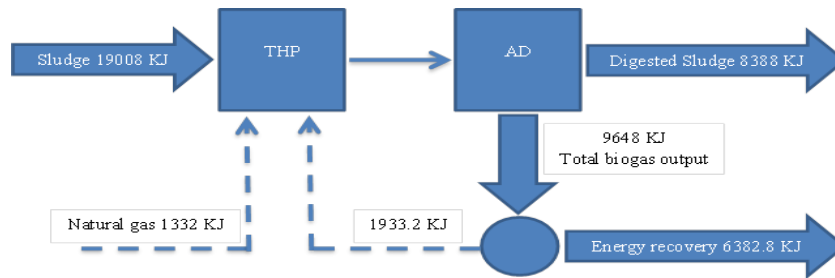*Figure 1. Energy flows for conventional AD (1Kg dry solid/h) [2]*

Figure 2. Energy flows for AD and THP (1Kg dry solid/h) [2]

3 THERMAL HYDROLYSIS PROCESS AND ANAEROBIC DIGESTION

Anaerobic digestion installations have poor energy recovery and require large assets. Therefore, thermal hydrolysis process (THP) has been developed to improve the digestibility of sewage sludge, increasing methane production in AD, energy efficiency, and operating cost. However, the increase in biogas yield because of the combination of AD and TH processes does not necessarily result in an overall net increase in energy per digested sludge. Figure 2 shows the energy flow for a typical configuration.

4 THERMAL HYDROLYSIS PROCESS, ANAEROBIC DIGESTION AND SLUDGE DRYING

To access the considerable chemical energy remaining in the sludge after AD, the sludge can either be burnt or be dried to produce a solid fuel product [9, 10]. The thermal drying process is the most energy-intensive one during the biofuel production, accounting for about 70% of the total energy consumption [11, 12]. Thus, one of the efficient ways to save energy is to remove more water from the sludge during the TH and AD processes. High heat value of the solid fuel could prove the fact that the combination of these processes could be cost effective.
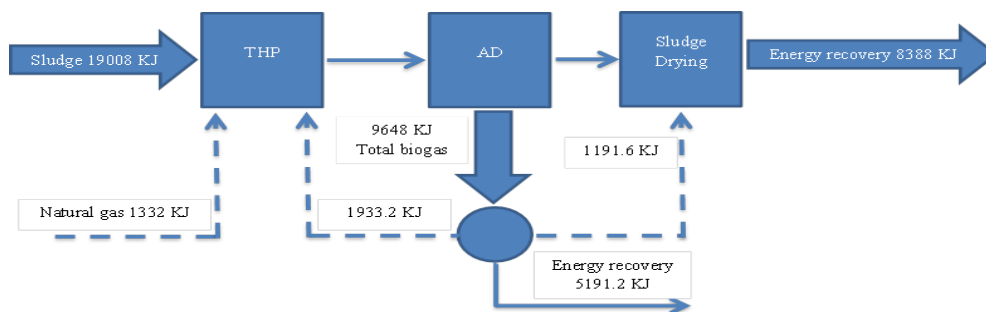

Figure 3. Energy flows for AD, THP and sludge drying (1Kg dry solid/h) [2]
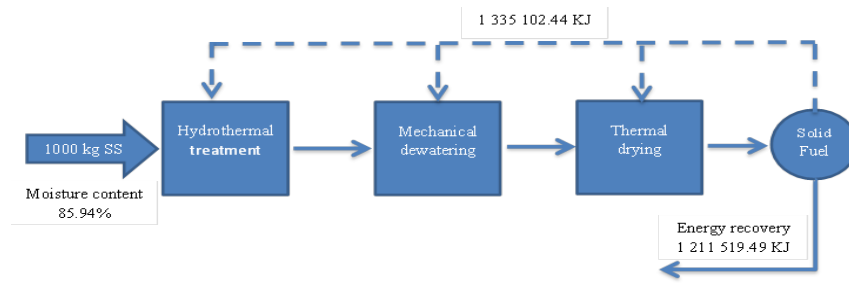
Figure 4. Energy flows for HTP and sludge drying (capacity 1t/batch, 30 min) [3]

5 THERMAL HYDROLYSIS AND SLUDGE DRYING

The hydrothermal (HT) conversion has bright perspective with three main merits: (1) largely improving the dewaterability; (2) dramatically reduction in volume, especially for the municipal solid waste (MSW); (3) energy densification. Energy contents of the solid biofuel from primary sludge carbonized at 140-200°C for 4h ranged from 21.5 to 23.31 MJ/kg, and kept increasing with carbonization [13]. Figure 4 illustrates an energy balance of the proposed process (capacity 1t/batch) producing solid biofuel under a temperature of 200°C and holding time of 30 min. it clearly shows that the HT pretreatment could be used to produce solid biofuel to recover energy from high moist sewage sludge.

6 PYROLYSIS

The pyrolysis plant shown in Figure 5 is concerned with bio-oil produced by fast pyrolysis of biomass. The heart of the system is a bubbling fluidized bed which is indirectly heated to 500°C by exhaust gases from a combustor that burns pyrolysis gas and some of the byproduct char [14]. The pyrolysis products (fine particles of solid char, vapors, aerosols, and gasses) leave the reactor with the circulating gas. The char is removed by one or more cyclone separators. The remaining pyrolysis products are then quenched with cool bio-oil which condenses the vapors to form bio-oil. Then the non-condensable gases are blown back into the reactor as fluidizing gases for the fluidized bed.
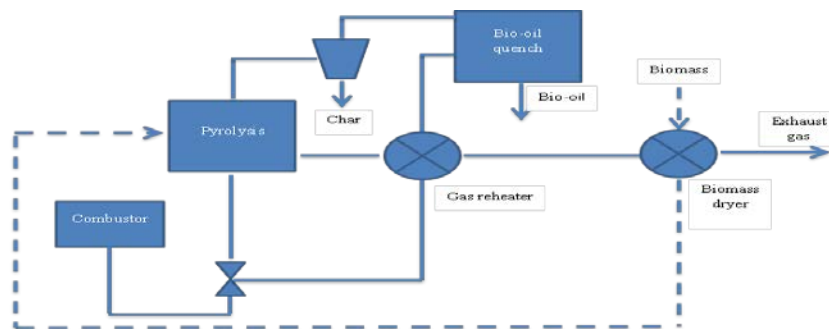

Figure 5. Pyrolysis [4]

7 COMPARISON OF ALL ENERGY FLOW PATHWAYS

Figs1-5 display the summary diagrams for the energy flows in each scenario (note that electricity, road fuel and consumables are not shown but included in the results). Table 1 and Table 2 show all the input and output energy results in more detail. Recovery ratio α is defined as the ratio of the gross energy recovered to total energy generated from the plant. The energy generated from the plant could be in the form of bio oil, bio solid, and bio gas. α ratio could be used as one of the main parameters to compare the energy consumption of the processes. The energy recovery also is defined as the total energy content of all kinds of bio fuels which has been subtracted from total energy consumption of the process such as electricity and thermal requirement.

Table 2 shows the energy consumption and generation of the 5 processes. Based on the data of the table the processes with thermal drying have the highest level of energy input around 9000 KJ/Kg. because of this intense increase in energy consumption of the process, THP sludge drying process has the lowest energy recovery ratio 47% among the other processes. Table 1 illustrates that Conventional anaerobic digestion (AD) has the lowest energy content because there is no pretreatment and the digestate will be disposed without using its energy. As a result, although THP demands an input of high grade heat and additional electrical energy, when compared with conventional AD, using a thermal hydrolysis (THP) as pretreatment sludge processing could increase the energy content of AD by 17%. To access the considerable chemical energy remaining in the digested sludge, the sludge could be dried to produce a solid fuel product [9]. The use of this process could result in 60% rise in energy recovery which is considerable. The pyrolysis process is optimized to produce the maximum liquid yield which has the highest calorific value (CV) around 19-23 MJ/Kg [15] in comparison with the other products and it is the main reason that the energy recovery of the process is 14800 KJ/Kg. Though the electricity consumption of pyrolysis plants is significant and needs to be considered, the process seems to be feasible in larger capacities.

Table 1. Evaluation of energy recovery from fuel production for 1kg dry solid feed

Process Type	Energy Recovery KJ	α , Recovery Ratio (%)
AD	5472	79
THP,AD	6382.8	66
THP,AD, sludge drying	13579.2	75
THP, sludge drying	8616.78	47
pyrolysis	14836	74

Table 2. Results of energy analysis for the pathways for 1kg dry solid feed

Energy	units	AD	THP, AD	THP, AD, sludge drying	THP, sludge drying	pyrolysis
INPUTS						
Electricity	KJ	486	644.4	756	-	864
Natural gas and thermal requirement	KJ	-	1332	1332	9495.7	4300
OUTPUTS						
Bio gas	KJ	6912	9648	9648	-	940
Bio oil	KJ	-	-	-	-	13200
Bio solid/Char	KJ	-	-	8388	18112.53	5900

8 CONCLUSIONS

This work focused on the energy balance of biofuel production from sewage sludge (SS) by different processes in order to illustrate the energy efficiency of new technologies. AD is widespread and an effective sludge treatment technique for the water industry and the combination of the other thermal processes with AD could increase the energy recovery of the plant. The study has found that both pyrolysis pathway and ADP with the use of TH pretreatment and sludge drying have the highest level of energy recovery and recovery ratio which could be beneficial to produce bio fuel. It is clear that improving processes and technologies are enabling significant opportunities for further energy recovery from sludge.

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