Commercial Demonstration of Solid Fuel Production from Municipal Solid Waste and Sewage Sludge Employing the Hydrothermal Technology

Kunio Yoshikawa

Professor, School of Environment and Society, Tokyo Institute of Technology
4259 Nagatsuta, Midori-ku, Yokohama, Kanagawa 226-8502, Japan
Email: yoshikawa.k.aa@m.titech.ac.jp, Tel:+81459245507, Fax: +81459245518

Abstract

In order to utilize solid wastes effectively, pre-treatments are essential. These are crushing, drying and deodorizing, which are disparate processes. But an innovative pre-treatment system called hydrothermal technology (HT) has been developed which performs these three pre-treatment functions in one process utilizing high pressure saturated steam. Any combustible wastes such as municipal solid wastes (MSW), plastics, food residue, animal manure, sewage sludge, etc. as received are fed into the reactor using conveyer or pumping systems. Saturated steam at 200-220℃, 1.6-2.5MPa produced in a boiler fueled by only part of the solid fuel product is injected into the reactor for about 60 minutes. This technology is also characterized by low energy consumption for drying. In this paper, commercial operational data of HT for MSW (50tons/day scale) and sewage sludge (100tons/day scale) are reported focusing on the mass and energy balances of the total process.

Keywords: hydrothermal technology, solid fuel production, municipal solid waste, sewage sludge

Introduction

Municipal solid waste (MSW) has become a severe problem in many countries, not only in developing countries but also in developed countries due to the limited lifetime of final waste disposal. Current waste treatment technologies are still not able to eliminate the waste while meeting three conditions: environmentally friendly, economically feasible, and high processing capacity. Thus, a method based on the aforementioned conditions should be developed for treating MSW. On the other hand, the combination of global population and energy demand in the near future will dramatically decrease the fossil resources, which will result in increasing of the energy price. Worsen with the increasing price of crude oil, many industries are now using coal; this has resulted in a significant increase in the demand and also in the price of coal. These two conditions would lead to a big opportunity for alternative solid fuel from MSW to replace or partially substitute coal as the main fuel. The problem due to large quantities of MSW can be solved by treating MSW, and thus the treated MSW having combustion characteristics similar to that of coal can be supplied as solid fuel needed for the industries.

MSW needs to be pre-treated for ease of use as a fuel resource. Pre-treatment of wastes requires crushing, drying and deodorizing, which are normally different processes. But we have developed innovative hydrothermal technology (HT) which can perform these three pre-treatment functions in one process utilizing high pressure saturated steam [1]. It was proven that MSW can be co-combusted with coal at certain blend ratios in previous experiments [2], and it was also shown that the devolatilization properties of coal were improved [3]. And also the increase of the fixed carbon content and the decrease of carbon and hydrogen contents due to the loss of volatile matter and ash in the washing process of the hydrothermal product were reported [4]. HT of MSW was investigated over a very wide range of temperatures (175–450 °C) and reaction times (up to 60 min), using a batch reactor system [5]. The results showed that the heating value of the hydrothermally treated MSW was comparable to low rank coals and it had a good drying performance, which are also reported in other research [6]. Considering its advantages, the HT system can be considered as an alternative MSW treatment to produce coal-like solid fuel in order to reduce the usage of fossil fuel for combustion.

Sewage sludge treatment and disposal is one of the focus points in the waste treatment technology research due to the fact that sewage sludge is a form of pollution and able to threaten people's lives if not treated properly. It is putrescible, has a foul smell, and in addition to large amounts of pollutant precursors such as proteins, fats and other organic compounds, it also contains large amount of pathogenic organisms, parasites, salts and heavy metals, as well as polychlorinated biphenyls, dioxins, radio nuclides and other components that are difficult to decompose. Incineration is one of the promising methods of sewage sludge treatment. Co-combustion of coal and sludge, or sole combustion of sludge in the incinerator can generate heat and power, reducing conventional fossil fuel consumption and greenhouse gas emissions. Incineration also resulted in maximum sludge reduction (up to about

95%), and during the process all the pathogenic bacteria is eliminated, and toxic organic residues are oxidized and decomposed by heat. At the end of the process, the incineration ash is used as raw material for cement and other construction materials production, so that heavy metals can be consolidated in concrete to avoid their release to the environment. Since sewage sludge is consisted mainly of water, the main technical challenge of sewage sludge treatment by incineration is to establish the dehydration technology with minimum usage of energy.

Tokyo Institute of Technology has been investigating sewage sludge HT system, resulted in improved natural drying performance and reduced odor [7-9], and a recent research confirmed that NO reduction occurred on the hydrothermally-treated sludge compared to untreated sludge [10]. In this system, the sludge with 80% moisture content is inserted into a sealed reactor and heated using 150 – 300 °C saturated steam. The moisture content of sewage sludge after the hydrothermal treatment and mechanical dewatering can be reduced down to 50%. After natural drying, the moisture content drops to less than 20% and the obtained solid fuel can be directly sent to incinerators. The heat produced from the combustion in the incinerator will be used to produce steam required for the hydrothermal process, while the waste water produced during the dehydration process will be sent to an anaerobic treatment to fulfill the water standards.

In this paper, commercial operational data of HT for MSW (50tons/day scale, Indonesia) and sewage sludge (100tons/day scale, China) are reported focusing on the mass and energy balances of the total process.

Operating Principle of the Hydrothermal Technology

Figure 1 shows the operating principle of HT for MSW treatment. Solid wastes (any combustible wastes such as MSW, plastics, food residue, animal manure, sewage sludge, etc.) as received are fed into the reactor using conveyer or pumping systems. Saturated steam at 200-220°C, 1.6-2.5MPa produced in a boiler fueled by only 10-15% of the solid fuel product is injected into the reactor for about 60 minutes. The reactor blades rotate for about 10-30 minutes to achieve uniform mixing. The product is discharged after extracting steam. In the case of mixed wastes such as MSW and agricultural wastes such as rice straw, the raw wastes of various sizes become powdery material. The water content however remains about the same as that of the raw material. The powdery product is subsequently dried by ambient air or by air blowing. Drying carried out using natural energy results in low energy consumption. The product is almost odorless and with the heating value of about 2/3 of coal. These can be used for co-firing with coal in boilers for power generation or heat supply.

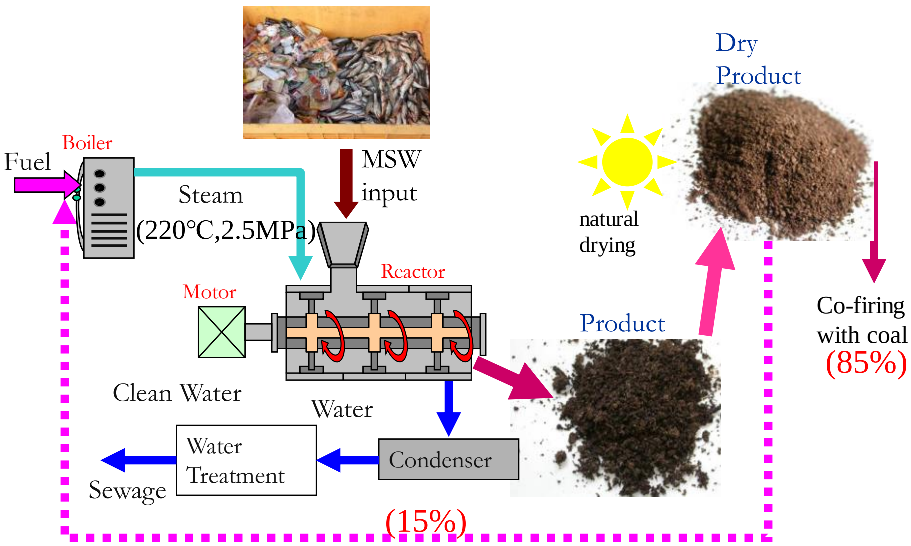


Fig. 1. Operating principle of the hydrothermal technology

On the other hand, in the case of high moisture content biomass wastes such as sewage sludge, animal manure and food residue, the product obtained by the HT process is not solid but slurry-like material whose water content is higher than the raw material. But this slurry-like product shows significantly improved dehydration performance compared with the raw material, and the mechanical dehydration of the product will produce separated water and solid residue with the water content less than 60%. The solid residue shows good drying performance as in the case of mixed waste product, and we can obtain dried powdery product. About 20-30 % of solid component is dissolved in the separated water, and the separated water contains much nutrients such as N, P and K. The heavy metal content which may reside in the raw sewage sludge is left in the solid residue, so the separated water can be utilized as pathogen and heavy metal free organic liquid fertilizer after diluting with 30-50 times large amount of water or utilized for biogas production by the anaerobic digestion process. If the raw material is food residue, the dried solid residue can be utilized as feed for livestock because amino acid increases by the hydrolysis reaction. If the raw material is animal manure or sewage sludge with less heavy metal content, the dried solid residue can be utilized as solid fertilizer. If the raw material is sewage sludge with substantial heavy metal content, the dried solid reside can be utilized as fuel for co-firing with coal.

Commercial Operation of the Hydrothermal Technology for MSW

We have been operating the first commercial HT plant with the capacity of 50 tons/day for four years in Indonesia and found that HT is a suitable MSW treatment technology for Indonesia due to its acceptance of non-segregated and high moisture content MSW. The aim of this paper is to present a comprehensive data set of the plant focusing on the HT product properties and the mass & energy balance analysis of the plant for optimizing the operation conditions of the plant.

In our commercial plant, the main components are the reactor, the boiler and the steam condenser. The reactor is a pressure vessel with the inner volume of 10 m^3, whose photo is shown in Fig.2. High pressure steam is supplied into the reactor for treating MSW. The reactor consists of two valves, one is for supplying MSW into the reactor from the top and another is for discharging treated MSW after the treatment from the bottom. A screw type rotor is fitted inside the reactor, which can rotate in either directions by an electric motor. The uniformity of the treatment throughout the MSW feedstock was ensured by this rotor. The boiler with the capacity of 2 tons/hour uses a part of dried HTT product of MSW as a fuel, whose amount is about 10-15% of the total produced amount. The boiler can supply medium-pressure saturated steam with the pressure of 2-2.8 MPa. The steam condenser is an ejector type indirect water cooled one, being used to condense the released steam from the reactor after the treatment. It also functions as an ejector to remove steam from the reactor. And then from the condenser, the condensed water is treated using the waste water treatment. The waste water treatment has been done using the honey comb waste water treatment with four sections. This is utilized to reduce the total dissolved solid in the waste water. After the forth section, water is streamed to the wetland area. In the wetland area, the pH stabilization, the reduction of the biological oxygen demand (BOD), the reduction the chemical oxygen demand (COD) as well as the removal of the total suspended solids (TSS) are done. For the last of the waste water treatment, we have bioindicators to check the water pollution.

In this batch-type treatment, MSW was fed into the reactor with supplying 2.5 MPa saturated steam into the reactor gradually from the boiler while being stirred by the rotor unit. The treatment temperature was around 180-230 °C. After reaching the target temperature, the reactor was held at the set temperature for 30 and 45 minutes. When the holding time finished, steam supply was stopped and the pressurized steam inside the reactor was discharged to the condenser until the reactor reached the atmospheric pressure. Then, the treated products were extracted from the reactor and naturally-dried in the greenhouse for about 2 days to obtain dried products for further analyses.

Fig. 2. Photo of the commercial HT plant for MSW

In this plant, non-segregated MSW whose typical composition is shown in Table 1 is converted into powdery solid fuel whose analysis result is shown in Table 2. Regardless of the daily fluctuation of the MSW composition, almost uniform solid fuel can be produced whose heating value is similar to lignite. Figures.3 and 4 show the typical mass and energy balances of this plant. In Fig.4, the energy content of MSW (dry-base) was taken as 100% for the energy balance calculation. This figure clearly shows that the energy requirement for steam production is less than 15% of the energy content of MSW and only a part of produced fuel is enough for the steam supply.

Table 1. MSW composition

Classification	Waste Composition (%)
Organic	59
Paper	23
Diapers	2
Plastic	13
Etc	3

Table 2. Proximate and ultimate analysis results of the product

Total Moisture (%)	4.7
Proximate Analysis (%)	
Volatile Matter	66.6
Fixed Carbon	15.3
Ash	13.4
Elemental analysis (%)	
C	45.2
H	6.0
N	1.8
S	1.7
O (diff)	27.3
HHV (MJ kg^{-1})	17.9

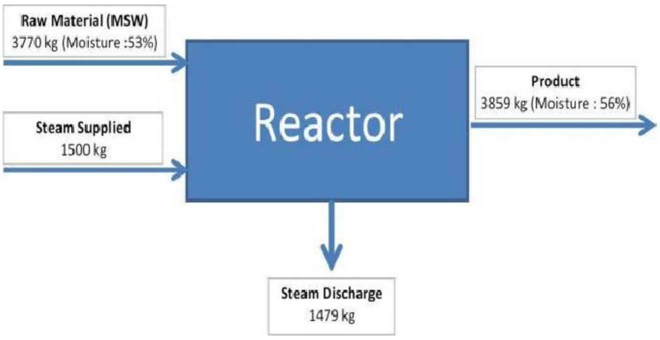


Fig.3. Mass balance of the HT plant

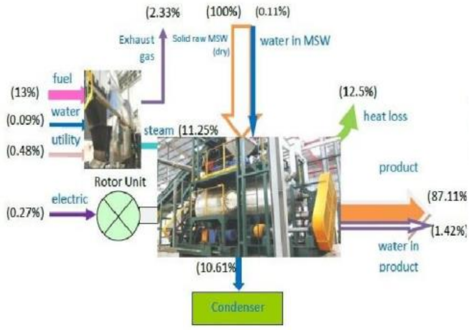


Fig.4. Energy balance of the HT plant

Commercial Operation of the Hydrothermal Technology for Sewage Sludge

In China, a 100 ton/day large-scale commercial plant was built in Qingdao, with the process flow diagram shown in Fig.5. Some photos of the main components are shown in Fig.6. Three 7.8 m^3 hydrothermal reactors were adopted to conduct an intermittent alternant type of the reaction, with each reactor capable of disposing 4.17 t for each batch. The processing time for each batch was approximately 105min, and each reactor ran 24 h a day. The steam required in the reaction was supplied by a steam boiler. After the hydrothermal treatment, sludge was transported to the buffer tank and then mechanically dehydrated by the plate and frame presser after the temperature dropped below 80 °C. After the dehydration, the sludge was transported to the boiler for burning as solid fuel. The separated liquid was discharged after the anaerobic treatment, whereas the biogas generated from the anaerobic process was transported to the steam boiler for recycling. The spent steam generated in the system was discharged after the deodorization treatment.

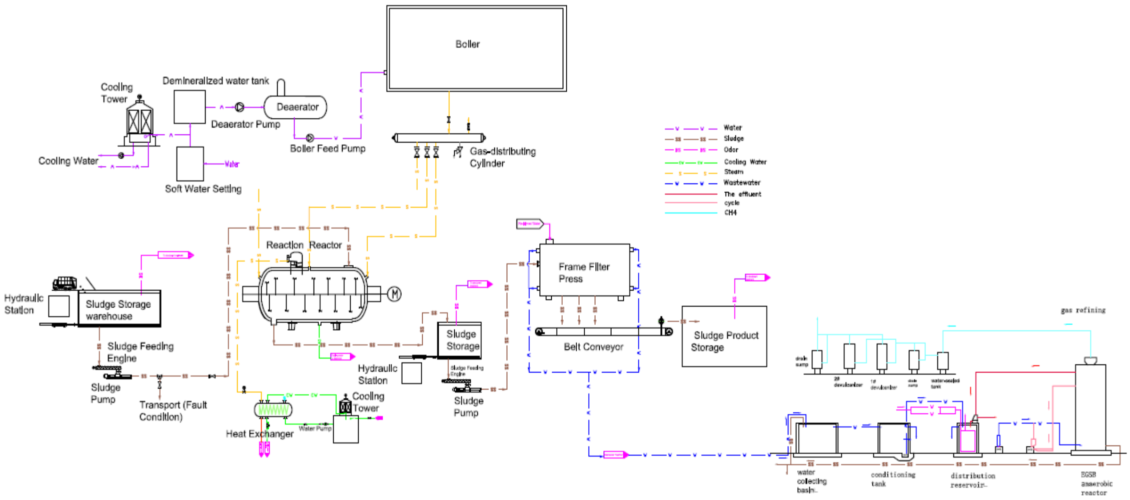
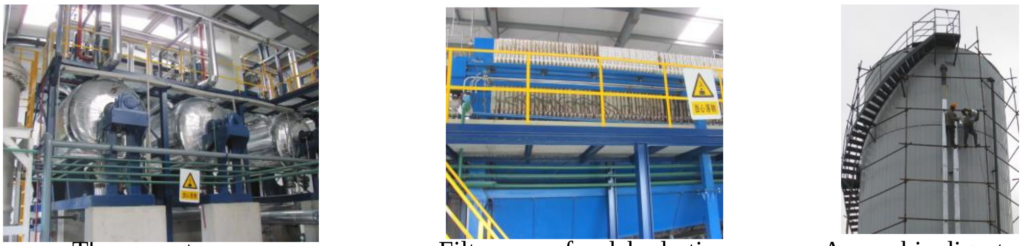


Fig.5. Process flow of the commercial HT plant for sewage sludge



Three reactors Filter press for dehydration Anaerobic digester

Fig.6. Some photos of the commercial HT plant for sewage sludge

Sludge hydrothermal system

First, the handling capacity of each batch was 4200kg; 4200 kg of sludge with 82.3% moisture content was placed in the hydrothermal reactor to facilitate a reaction through the sludge pump. Second, 4200Kg of sludge was preheated in the jacket, and temperature rose from room temperature (20 °C) to 95 °C. Steam was added, and the hydrothermal treatment proceeded. The sludge temperature rose from 95 °C to 190 °C. The saturated steam at 200 °C was used to heat the sludge, and the enthalpy value was 2798 kJ/kg. Measured steam consumption was 1758 kg.

Sludge dewatering system

The solid attrition rate of the mechanical dehydrator was 9.9% according to the measured value. The moisture content of sludge cake was 35.7% after the dehydration, and the amount of sludge that entered the mechanical dehydrator after the hydrothermal treatment was 4476 kg. The dehydrated product of sludge was 1041kg, and the separated liquid was 3435 kg.

EGSB anaerobic digestion unit

The amount of the separated liquid produced by the mechanical dehydration was 3435 kg. According to the operation results of EGSB, the obtained separated liquid of 4.2 t could produce 20.06 m³ of biogas with the methane purity of 60%.

In order to reduce the steam consumption and increase the energy efficiency, three reactors were operated with different operational phases as shown in Fig.7 to supply part of the extracted steam from one reactor to another reactor as shown in Fig.8

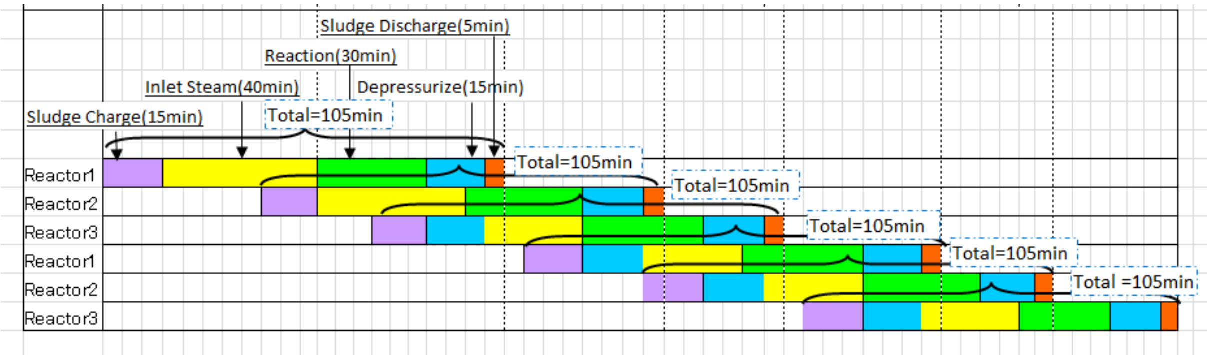


Fig.7 Sequencing of three reactors working time for energy saving

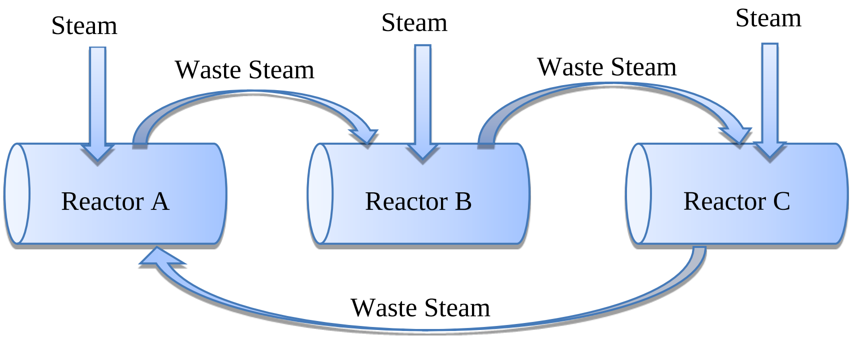


Fig.8 Steam recycling concept for energy saving

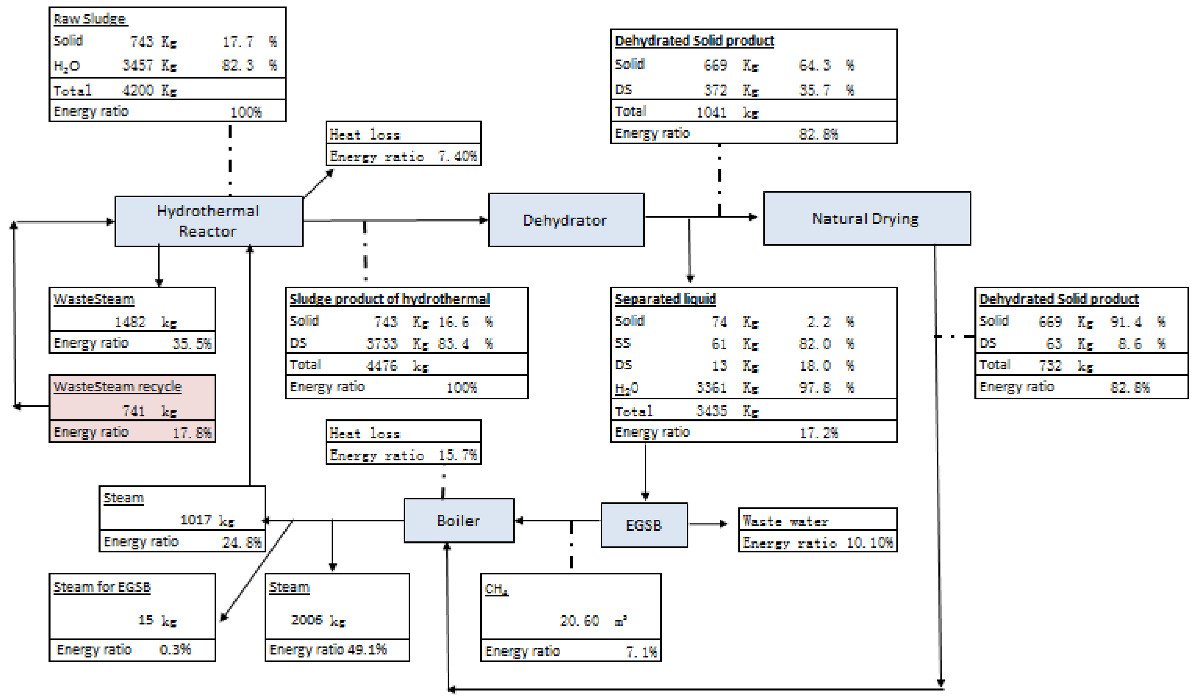


Fig.9 Mass and energy balances at the reaction temperature of 190 °C and the reaction time of 30 minutes

Fig.9 shows the mass and energy balance data under the reaction temperature of 190℃ and the reaction time of 30 minutes. Here, the total energy content in the raw sludge is assumed to be 100%, and the energy content of each substance is shown by relative %.

The sludge is usually composed of 80% of water and 20% of solid material. Sludge Energy ：Energy content in sludge (=dry sludge weight × dry base heating value of the solid material)

Steam Energy ：Energy content in steam (=consumed steam weight × enthalpy of steam)

According to the relationship between the energy input and output, the consumed energy was used to heat up sludge. Fig.9 shows that the energy input was the energy consumption for sludge heating during the hydrothermal treatment process. According to the data obtained from the operation conditions, with the processing capacity of the single batch of 4200 kg, the heating process to the target temperature of 190°C requires 1017kg of saturated steam and 741kg of the waste steam.

The energy output included the usage of the anaerobically produced biogas from the separated liquid and the dewatered sludge as fuel in two parts. According to the EGSB operation result, 4200kg sludge could produce 20.06 m^3 biogas from the separated liquid with methane purity of 60%. The sludge product with the moisture content of 35.7% was 1041kg, whose heating value was 14.19×10^3 kJ/kg.

According to the energy-saving system operation conditions, 4200kg sewage sludge with the moisture content of 82.7% was treated, and about 50% waste steam recycling (741kg) for heating sewage sludge was available. Where about 24.8% (1017kg) of steam was used for the hydrothermal treatment of sludge and about 0.3% (15kg) of steam was used for EGSB warming with 35℃. There were still about 49.1% (2006kg) saturated steam left which could be utilized to create additional value.

Summary

We have successfully built and operated world first commercial HT plants to produce uniform and dried solid fuel from non-segregated MSW and high moisture content sewage sludge with high energy efficiencies . The produced solid fuel showed the similar crushing performance with coal which enables us to co-fire with coal easily. HT can be applicable to any kinds of biomass resources to convert them into coal-alternative fuels and co-firing of such fuels with coal would be one of the most effective and economical measures to reduce CO_2 emission associated with coal combustion.

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