Commercial Demonstration of Solid Fuel Production from Municipal Solid Waste Employing the Hydrothermal Treatment

Tri Sesilia Safril[1,2,*], Bayu Indrawan Safril[1,2], Kunio Yoshikawa[2]

1. R.Bachsan Siagian 74, Tambak Sari, Jambi Selatan, Jambi 36138, Indonesia
2. School of Environment and Society, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan

*Corresponding author

*Abstract***:** This work aims to report the first commercial demonstration of solid fuel production from non-segregated municipal solid waste (MSW) employing the hydrothermal treatment (HTT) in Indonesia. The process starts from the supply of non-segregated MSW into the reactor, and then 220℃, 2.5MPa saturated steam is supplied into the reactor and the blades installed inside the reactor rotates to mix MSW and steam for about 30 minutes. Then the product is discharged after extracting steam. The product is powder-like substance and the moisture content is almost the same as the raw material, but is easily dried by natural drying. The inert material such as metal, glass and stones can be easily sieved out after drying. There is almost no bad smell in the solid products, and the products can be used as solid fuels which can be mixed with coal for power generation or cement production. Only 10-15% of the product is enough for steam production in a boiler. This study focuses on the product properties and mass & energy balances of the HTT commercial plant located in Indonesia with the treatment capacity of 50 tons/day.

Keywords: Hydrothermal Treatment, Municipal Solid Waste, Solid Fuel Production;

1. INTRODUCTION

Indonesia's high population and rapid industrialisation present serious environmental issues, which are often given a lower priority due to high poverty levels and weak, under-resourced governance. Issues include large-scale deforestation (much of it illegal) and related wildfires causing heavy smog over parts of western Indonesia, over-exploitation of marine resources; and environmental problems associated with rapid urbanization and economic development, including air pollution, traffic congestion, garbage management, and reliable water and waste water services are becoming serious.

Especially in the capital of Indonesia, Jakarta, the environmental problems increase day by day. Municipal solid waste (MSW) in Jakarta has reached a crisis point. MSW is mostly disposed of in landfills by the open dumping method and this creates numerous environmental problems. The problem of MSW management is much more acute in metropolitan cities like Jakarta where land available for landfilling is scarce.

Presently, Jakarta generates approximately 7000 tons of MSW every day which is likely to increase day by day. Due to the difficulty of getting the public acceptance of MSW incinerators as well as the MSW segregation, an advanced non-incineration based technology with the benefit of recovering energy from MSW without segregation is a promising alternative for solving the waste disposal complexity in developing countries.

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 treatment technology (HTT) which can perform these three pre-treatment functions in one process utilizing high pressure saturated steam[1]. It was proven that

[1] Pandji Prawisudha, Tomoaki Namioka and Kunio Yoshikawa, Coal alternative fuel production from municipal solid wastes employing hydrothermal treatment, Applied Energy, 90 (2012) 298-304.

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 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]. The research on HTT for MSW incineration fly ash to reduce the dioxin content showed that a higher HTT reaction temperature is the most important[5]. HTT 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[6]. 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[7]. Considering its advantages, the HTT 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.

We have been operating the first commercial HTT plant with the capacity of 50 tons/day for one year in Indonesia and found that HTT 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 HTT product properties and the mass & energy balance analysis of the plant for optimizing the operation conditions of the plant.

2. HYDROTHERMAL TREATMENT

HTT is the combined use of water (hydro) and heat to convert the waste into usable products. Some are also categorized as a thermal treatment. HTT developed by our research team can convert the high water content solid waste into dry uniform powder solid fuel having similar properties of young coal.

Figure 1 shows the operating principle of HTT. Non-segregated MSW are fed into the reactor, and then, 220°C, 2.5MPa[8] saturated steam is supplied into the reactor and the blades installed inside the reactor rotates to mix MSW and steam for about 30 minutes. Then the product is discharged after extracting steam. The product is powder-like substance and the moisture content is almost the same as the raw material, but is easily dried by natural drying. The inert material such as metal, glass and stones can be easily sieved out after drying. There is almost no bad smell in the solid products, and the products can be used as solid fuels which can be mixed with coal for power generation or cement production. Only 10-15% of the product is enough for steam production in a boiler.

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Fig. 1. Operating principle of HTT in Indonesia

During HTT, the bound water in the cells of MSW becomes free water by destroying the cell walls under the hydrolysis reaction with steam. Hence in principle, this treatment itself is not a drying process, but will enhance the drying process by changing the bound water into the free water so that the surface moisture removal is made easy and accelerated.

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. 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.

3. OPERATIONAL METHOD

3.1 APPARATUS AND EXPERIMENTAL PROCEDURE

The hydrothermal treatment of MSW was performed using the reactor shown in Fig. 2.

Fig.2. The reactor for the hydrothermal treatment installed in Tangerang, Indonesia

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.

3.2 RAW MATERIAL

MSW to be processed at the factory comes from various sources in the nearby newly developed area (Summarecon Serpong). Sources of waste in the area can be grouped into residential areas (clusters, shophouses and dormitories), markets (malls and markets), hospitals, education and commercial areas. It was consisted of food residue, paper, plastic, diaper, etc (components such as glass, metal, textile, styrofoam, canned, B3 wood, rubber and others were in negligible amounts). The detail composition of MSW is shown in Table 1, which indicates that the major composition was organic. Percentage of composition of organic waste reached 59% of total waste. Other wastes are paper, plastic and others as shown in Table 1.

Table 1 Composition of MSW in Summarecon Serpong

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

4. RESULTS AND DISCUSSION

4.1 PROXIMATE AND ULTIMATE ANALYSIS

The proximate and ultimate analysis data of the hydrothermally treated MSW are presented in Table 2.

Table 2. Proximate and Ultimate Analysis

Properties	MSW Processed
Proximate Analysis (%)	
Moisture	4.7
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

At first, the resulting product does contain water. However, after being naturally dried, the resultant product can be used as fuel. A part of this product is used as a fuel for the boiler. With 4.7% moisture content and the high heating value of 17.9 MJ Kg-1, the rest of the products are sold as coal alternative solid fuel.

4.2 ENERGY AND MASS BALANCE

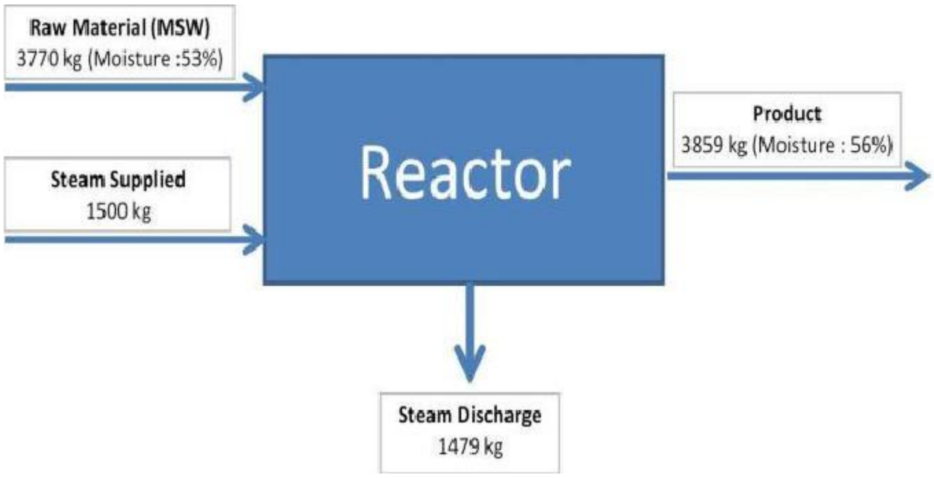

Fig 3. Mass balance with 30 min. holding time

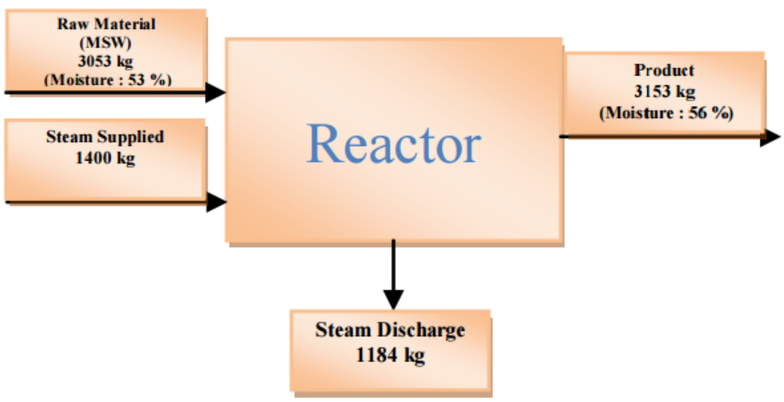

Figure 4. Mass balance with 45 min. holding time

Figs.3 and 4 compare the mass balance analysis results for the cases of the holding time of 30 minutes and 45 minutes. By increasing the holding time, steam supply per unit mass of MSW increased but the product properties were not so different. So we can conclude that the holding time of 30 minutes is enough.

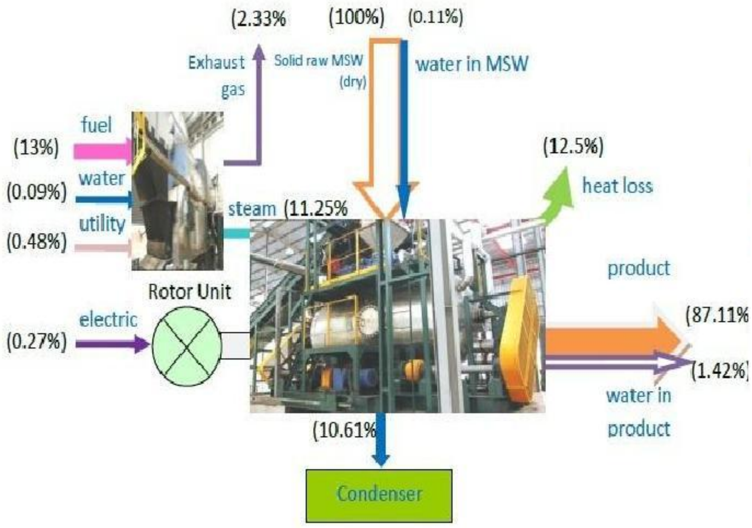

Fig. 5. Energy balance with 30 min. holding time

Figs.5 and 6 compare the energy balance analysis results for the cases of the holding time of 30 minutes and 45 minutes. Here, the energy content of MSW (dry-base) was taken as 100% for the energy balance calculation. The energy required for the boiler fuel can be calculated based on the water and steam enthalpy difference through the boiler combined with the claimed boiler efficiency and utility. The energy loss in the steam condenser and the water content inside the product were also calculated based on their temperature. The heat loss was obtained from the difference in the total energy balance. These figures clearly show 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.

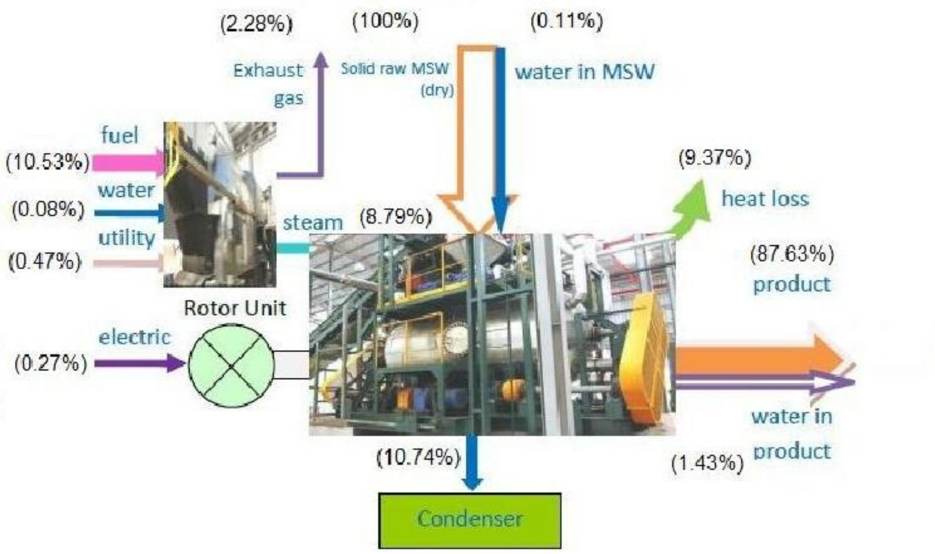

Fig. 6. Energy balance with 45 min. holding time

From the mass balance, we can see that the amount of steam discharged in the case of the 30 min. holding time was more than that in the case of the 45 min. holding time because the raw MSW were different type and mass. And in the energy balance, the heat loss in the case of the 30 min. holding time was 12.5 % and was higher than that in the case of the 45 min. holding time (9.4%). This is because that the steam input shall be increased when the plant is started from the cold state (in the case of the 30 min. holding time). If the reactor is already in the hot state, the pressure increase inside of the reactor can be faster than that when the reactor is in the cold state.

4.3 GAS EMISSION

The gas emission analysis data of the boiler flue gas after burning the hydrothermally treated MSW is presented in Table 3,

Table 3. Gas Emission Analysis

Parameter	Unit	Result	Quality Standard
Mercury (Hg)	mg/m^3	0.03	5
Amonia (NH_3)	mg/m^3	0.17	0.5
Antimon (Sb)	mg/m^3	< 0.01	8
Arsen (As)	mg/m^3	< 0.01	8
Chlorine (Cl_2)	mg/m^3	< 0.004	10
Hydrogen fluoride (HF)	mg/m^3	< 0.0003	10
Hydrochloric acid (HCl)	mg/m^3	< 0.0031	5
Cadmium (Cd)	mg/m^3	0.03	8
Nitrogen Dioxide (NO_2)	mg/m^3	7.8	1000
Opacity	%	< 20	35
Particulate	mg/m^3	25.7	350
Zinc (Zn)	mg/m^3	1.29	50
Sulfur dioxide (SO_2)	mg/m^3	81	800
Lead (Pb)	mg/m^3	0.10	12
Hydrogen Sulfide (H_2S)	mg/m^3	4.21	35

While there is no special gas treatment facilities in the flue gas line of the boiler expect for a cyclone, all the gas emission data satisfied the quality standard. The emission from the reactor was negligible, so these emission data show that HTT is environmentally more friendly than conventional incineration technologies.

5. SUMMARY

A commercial hydrothermal plant has been successfully operated in Indonesia for solid fuel production from non-segregated MSW for more than one year. With the reaction pressure of 2.5MPa and the holding time of 30 minutes, MSW can be converted into powder-like solid fuel with the heating value higher than 17 MJ/kg. The mass and energy balance analysis show that around 15% of the produced solid fuel is enough to supply the required amount of steam for the hydrothermal treatment, and the running cost of the plant is low. Also the gas emission data from the boiler demonstrates the low environmental impact of the hydrothermal treatment.

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