한국환경과학회지 제19권(제1호), 9~16, 2010
Journal of the Environmental Sciences

A Fuel Feasibility Study of Sewage Sludge by Melting of Thermoplastic Polyethylene

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(Manuscript received 23 November, 2009; revised 15 December, 2009; accepted 11 January, 2010)

Abstract

This pilot study evaluated fueling feasibility of sewage sludge, which contains a large amount of water content, by applying melting of thermoplastic polyethylene (PE). This study has identified a simultaneous achievement of drying and heating value improvement of the sewage sludge. The sewage sludge collected from a sewage sludge treatment plant during a winter period had a water content of 83.7 wt%, a combustible volatile content of 12.5 wt%, and an ash content of 3.8 wt%. The higher heating value (HHV) of the dried sewage sludge, before impregnation or coating of PE, was 4,600 kcal/kg. The collected sewage sludge was immersed into the melted PE solution, which had a HHV of 11,070 kcal/kg, and kept immersing with increasing reaction time. As the reaction (immersing or coating or impregnation) time increased, the water content of the sludge decreased. However, the HHV of the sludge increased with increasing the reaction time. The HHVs of the sewage sludge immersed or dipped into the melted PE solution for 15 min ranged from 6,780 to 8,170 kcal/kg with water content less than 7 wt%. This result indicates the melted PE solution can be utilized as an improvement technology for dryness and heating value of the sewage sludge with high water content. The sewage sludge impregnated or coated with melted PE can be utilized as potential fuel or energy resources.

Key Words : Sewage sludge, Melted PE, Drying, Heating value, Water content, Fuel

1. Introduction

A lot of different waste types, such as gas, liquid, and solid phases, have been accompanied by human life. The improvement of the quality of human life as well as rapid economic development in modern society has produced a large amount of sewage sludge. The current disposal methods[1~12)] of sewage sludge in Korea include ocean dumping of 68.5%, recycling of 18.5%, incineration of 10.9%, and landfilling of 2.1% in year 2007[2)]. Currently, ocean dumping is main methods to dispose of sewage sludge in Korea. In particular, 100% of sewage sludge is disposed of ocean dumping in Ulsan[3)]. Even though ocean dumping is one of the cheapest disposal methods, it would harmful to the marine environment[13,14)]. Therefore, ocean dumping of sewage sludge and hazardous[14~20)] wastewater may not be allowed any more after year 2012. The breakdown of the target disposal methods by 2011 in Korea[1,2)] is as follows: ocean dumping (0%), recycling (69.5%), incineration (29.0%), and landfilling (1.5%). Therefore, various regulations and financial aids to improve fraction of sewage sludge to be recycled have been considered.

As available energy resources such as fossil fuel are getting short, most countries in the world have been faced energy problems. A lot of studies to find energy or fuel resources from natural products or

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even wastes have been tried in numerous countries[2, 12~14]. Sewage sludge has been considered as just waste to be disposed of [3]. Sewage sludge has a large amount of organic components which could be utilized as energy or fuel resources. Thus, numerous researches have been conducted to utilize sewage sludge for getting useful energy forms[13,14,21~27]. However, one of main drawbacks for utilization of sewage sludge as fuel or energy resources was high water content[14,28~30]. Currently, most of sewage sludge produced from sewage treatment plants has water content above 80 wt%. Thus it is necessary to find effective or cheap drying method from sewage sludge. Another drawback of sewage sludge utilization for fuel or energy resources would be lower heating value as compared fossil fuel such as coal or oil. A lot of trial investigation to improve heating value has been conducted. However, it is not easy to improve heating value of sewage sludge. From these points of view, this study tried to utilize melted plastics with high heating value in order to solve simultaneously both drying and heating value problems which have sewage sludge. This pilot study identified a fueling feasibility of thermoplastic polyethylene for drying and heating value improvement of sewage sludge which had much higher water content above 80 wt%.

2. Materials and Methods

The investigated sewage sludge was obtained from B sewage treatment plant which is operated by a combined method of biological and chemical treatment. The sewage sludge used in this study was obtained after a preliminary dehydration using a centrifugal method from the treatment plant and it had water content of 83.7 wt%, volatile content of 12.5 wt%, and ash content of 3.8 wt%. The tested sewage sludge had higher heating value (HHV) of 4,608 kcal/kg based on dried status. A spherical shape of the tested sewage sludge of 3 g was manually prepared for dipping experiment into the melted plastics. The plastics (polyethylene (PE)) utilized in this study were obtained from D chemical which produces PE and polypropylene (PP). The plastics were a kind of virgin plastics which were not used for other purposes and not contaminated by other chemicals. The plastics (PE) of 200 g were melted in the reactor which was controlled at 220℃ under nitrogen atmosphere. The prepared sewage sludge was put into the melted PE solution in which temperature was maintained around 200 - 220℃ and nitrogen was purged before the reaction conducted. The sludge was floated on the surface of the melted plastics solution at the start of the immersing or dipping reaction and the floated status continued till around 10 min. As the sludge was contacted with the plastics solution, it started to rotate on the solution surface and to emit water vapor with bouncing out of the surface. The emission of the water vapor was very active during the first 5 min and it was still continued till 10 min. While the sludge was emitting water vapor and rotating on the solution surface, it was continuously coated or impregnated by melted plastics. In about 13 min reaction, including immersing, coating and impregnation, the sewage was submerged into the bottom section of the melted plastics solution. In 15 min reaction the sewage sludge was taken out of the solution and then got cooled to room temperature in the conditioned desiccators at relative humidity of 50 ±2%. Then the sewage sludge was sent to analytical laboratory for analysis of gravimetry, heating value, and content of moisture, volatile and ash.

3. Results

3.1. PE Phase transition and reaction temperature

Fig. 1 shows time required to melt the PE of 200 g under nitrogen atmosphere in the reactor. Exterior heat source, such as gas burner with constant flame conditions, was applied to the outside of the reactor

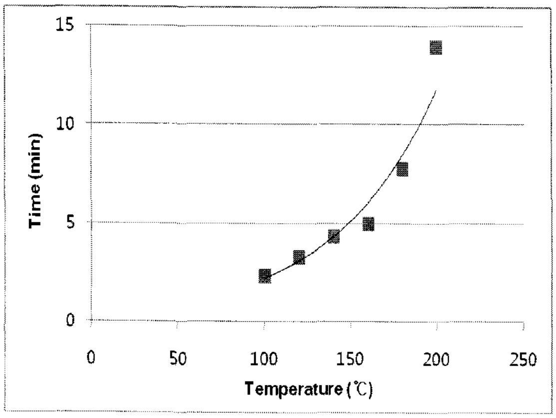

Fig. 1. Time required to rich the space temperature inside the reaction vessel.

and the air (space) temperature inside the reactor was monitored. When the temperature reached to around 35℃, there were initial emissions of gases or vapors. These emitted gases or vapors would not be from degradations from plastic chain of the PE, but some low molecular volatiles or vapors contained in the PE structure. The required time in order to raise the unit temperature inside the reactor space (air), the more time was needed as the temperature increased. This phenomenon may be associated with phase transition from solid to molten status of the PE. The crystalline melting temperature of PE was reported around 141 - 144℃[31,32]. Thus the more latent heat is required to convert from solid to liquid or melted (molten) status around the crystalline melting temperature of PE. As the temperature increased, there would be also increase heat boss, particularly after 180℃, due to the increasing temperature between the reactor and the environment. Thus more energy is necessary to get increased temperature of the reactor or melted PE solution.

In order to effectively coat or impregnate melted PE onto sewage sludge, it is necessary to get proper fluidity of the PE solution. When the temperature of the reactor space reached 200℃, the PE solution had proper fluidity for coating or impregnation. Even though the authors did not measure the viscosity of the PE solution, the proper reaction temperature for this study was selected to 220℃ based on several trial experiments. When the space temperature inside the reactor reached 220℃, the measured temperature of the melted PE solution was around 250℃. The PE solution at that temperature had much lower viscosity or proper fluidity apparently like water solution.

Fig. 2 shows the results of thermo gravimetry analysis (TGA) of the polyethylene that was used as a heating value modifier in this study. Major thermal degradation was occurred at the temperature region from 400 to 500℃. Before the PE reach to 400℃, there was almost no thermal degradation. The PE plastic chain will not be experienced thermal degradation under the reaction (PE solution) temperature, 250℃ (reactor space temperature of 220℃), selected for PE coating or impregnation onto sew sludge. Thus coated or impregnated PE onto sewage sludge may directly contribute to increasing the heat value of the sludge. Also, the reaction temperature is good enough to remove most of free water, capillary water, and surface water contained in sewage sludge. In reality, the reaction temperature or heat transfer rate thorough the reactor system could be affected by the amount of

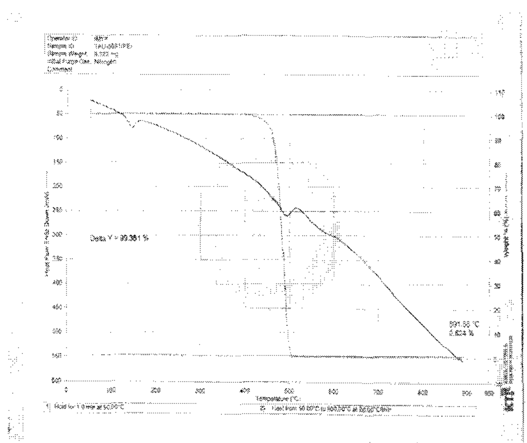

Fig. 2. Thermo gravimetry analysis of the polyethylene used for this study.

PE used for melting, reactor materials and shapes, types of heat sources. Also, the temperature range which can be maintained good fluidity of the reaction medium (melted PE solution) after sewage sludge was inserted into the reactor is easily affected by the amount and temperature of inserted sewage sludge. However, this study is a trial study for feasibility evaluation of drying and heating value improvement of moist sewage sludge. Thus this study did not consider that seriously these factors which could affect reaction conditions. However, these factors should be carefully considered for pilot-scale or real application of the melted PE solution for simultaneous purpose of drying and improvement of heating value of sewage sludge.

3.2. Fuel Characteristics vs. Reaction Time

3.2.1. 5 min reaction

Fig. 3 shows change in weight and heating value of sewage sludge as a function of reaction time in melted PE solution. Fig. 4 shows change in water content and volatile matter content of sewage sludge as a function of reaction time in melted PE solution.

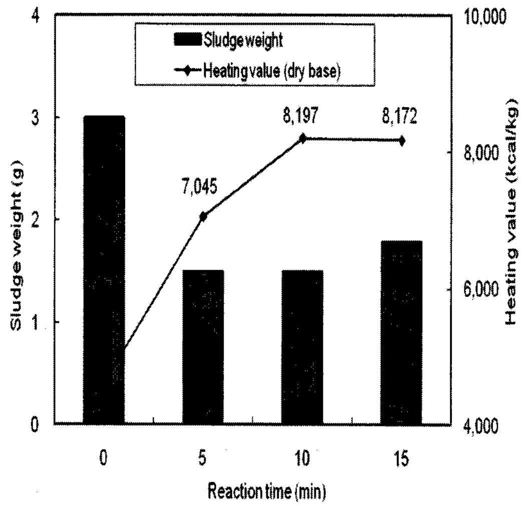

Fig. 3. A change of weight and heating value of the sewage sludge as a function of reaction time in melted PE solution.

In 5min of reaction time the higher heating value (HHV) of the sludge became 7,045 kcal/kg, which was an increase of 53%, as compared to the original sewage sludge based on dried status. The weight of the sludge in 5 min reduced to 50% of the original sludge weight. The water content of the sludge in 5 min became 23.6 wt% which is equivalent to 60.1 wt% in water content from the original sewage sludge of 83.7 wt%. When the sewage sludge was put into the melted PE solution, the water was vigorously exhausted from the sludge. In addition, the sludge was rotated on the melted PE solution and coated with melted PE forming thin PE film on the surface of the sludge while the contained water in the sludge was escaping from the sludge as water vapor phase.

Fig. 4 also shows a fraction change of combustible components of the sewage sludge as a function of reaction time in melted plastics solution. In 5 min reaction the combustible components of the sewage sludge increased to 64.6 wt% which is equivalent to increase of 52.1 wt% as compared to the original one. This increase represents PE was coated or impregnated on the surface or pores of the sludge while water was exhausting. The coated or impregnated PE can increase in content or fraction of combustible components resulting in increase of heating value of the sludge.

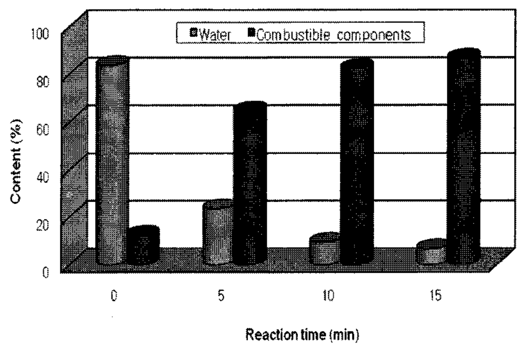

Fig. 4. A change of water and combustible content of sewage sludge as a function of reaction time in melted PE solution.

3.2.2. 10 min reaction

When the reaction time increased to 10 min, the weight of the sludge was not changed as compared to that in 5 min reaction. However, the heating value increased to 8,197 kcal/kg and the water content decreased to 9.7 wt%. This represents PE was additionally coated or impregnated on the surface or pores of the sludge as much as the amount of exhausted water vapor, resulting in increase of heating value even with no change of the total weight of the sludge coated with PE. The fraction of combustible components in the sludge experienced the reaction for 10 min increased to 82.3 wt%. Thus the increase in degree of coating or impregnation by PE with increasing reaction time is verified by the increase in combustible components.

3.2.3. 13 and 15 min reaction

As the reaction time passed 13min, the floating sludge was submerged into the bottom section of the melted PE solution. This represents increase in the density of the sludge coated or impregnated with PE as the reaction time increases. The density of the sludge until the reaction time becomes 13 min was lower than that of the melted PE solution. Thus the sludge was floated on the solution surface. However, there was continuous increase in the degree of coating or impregnation by PE as the reaction time increases. Thus the density of the sludge coated or impregnated with PE over 13 min got heavier than the density of the melted PE solution, resulting in submerging the sludge in the solution. This fact indicates there is proper reaction (immersing) time of the sewage sludge in melted PE solution.

In order to be utilized as alternative fuel resources, the sewage sludge needs to get economically coated or impregnated by PE. From the point of economic view, the proper coating or impregnation time can be 13 min in this study. In reality, there is a variation possibility in production or physicochemical characteristics of the sewage sludge obtained from wastewater treatment plants. Thus this study also investigated reaction characteristics for 15 min. For analysis of characteristics of the sewage sludge in 15 min reaction, the submerged sludge was taken out from the bottom of the melted PE solution. The heating value and moisture content of the sewage sludge product reacted for 15 min in the melted PE solution reaction were 8,172 kcal/kg and 6.7 wt%. The combustible components and ash contents of the sewage sludge reacted for 15 min in the melted PE solution 86.6 wt% and 6.7 wt%, respectively.

4. Discussion

Fig. 5 shows change trend of water content, combustible components content, and heating value of sewage sludge as a function of reaction time in melted PE solution. As reaction time increases, the water content in the sewage sludge rapidly degreases within 5 min reaction and then slowly and gradually decreases by 15 min reaction. The combustible matter content and heating value rapidly increased within 5 min reaction and then continuously increased by 15 min reaction. The combustible matter content and heating value, having a similar increase trend, of the sewage sludge-PE fuel obtained from this study

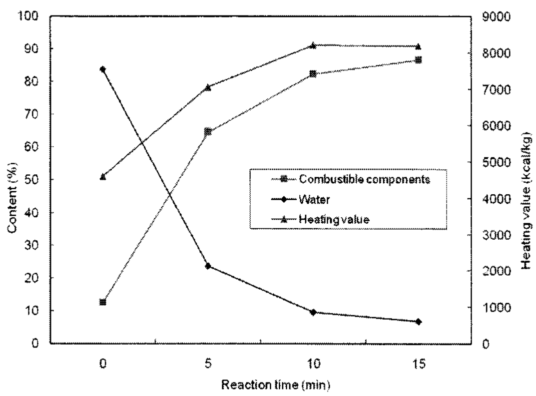

Fig. 5. A change trend of the characteristics of the sewage sludge reacted in melted PE.

showed an opposite trend to the water content with increasing reaction time. This represents the melted PE can fill in the holes or pores that water in the sewage sludge was escaped from. Thus the melted PE can be coated on the surfaces of the holes or pores and even the outside surfaces of the sewage sludge. The melted PE can be impregnated into the sludge structure through the holes or pores.

Table 1 summarized the criteria of class and quality of solid refuse fuel (SRF) or refuse derived fuel (RDF), which were promulgated on July 13, 2009 by the Korea Ministry of Environment, according to the regulations on resources saving and recycling promotion[33]. To be utilized as SRF or RDF, low heating values of potential fuel products must be equal to or higher than 3,500 kcal/kg according to the relevant regulations. However, their low heating values of RPF (refuse plastic fuel) and TDF (tire derived fuel) must be equal to or higher than 6,000 kcal/kg. In order to be classified as the 1st class of SRF or RDF, the sewage sludge-PE fuel must satisfy the following requirements: heating value above 6,500 kcal/kg, moisture regulation less than 10.0 wt%, ash content less than 20.0 wt%, chlorine content less than 0.50 wt%, and the heavy metals (Hg<1.20, Cd<2.0, Pb<200.0, As<2.0, and Cr< 30.0 mg/kg).

The sewage sludge-PE fuel obtained after reaction for 10 and 15 mins in the melted PE solution in this study showed heating values of 8,197 and 8,172 kcal/kg and moisture content of 9.7 and 6.7 wt%, respectively. These values can satisfy the regulations of heating value and moisture, concerning the 1st class of SRF or RDF required by the KME. The ash contents of the sewage sludge-PE fuel after reaction for 10 and 15 mins were 8.2 and 6.7 wt%, respectively. The sewage sludge usually shows much lower content of heavy metals and chlorine content than the guide lines of renewable fuels or wastes, such as SRF or RDF, suggested by KME. In addition, it would not be troubled to prepare sewage sludge-PE products for utilization as fuel resources. When evaluated based on the analysis values of the factors that should be considered to be utilized as potential fuel resources, the sewage sludge coated or impregnated with melted PE can fulfill the relevant regulations concerned SRFs or RDFs by KME. Thus the sewage sludge-PE fuel may have high potential or feasibility for utilization as alternative fuel resources to conventional fuel.

5. Conclusions

Through a feasibility study to utilize sewage sludge

Table 1. Criteria of class and quality of solid refuse or derived fuel in Korea(Amendments of the regulations on resources saving and recycling promotion, Korea Ministry of Environment, July 13, 2009)

Class	Heating Value* (kcal/kg)	Moisture (wt%)	Ash (wt%)	Chlorine (wt%)	Sulfur (wt%)	Heavy Metals (mg/kg)				
						Hg	Cd	Pb	As	Cr
I	> 6,500	< 10.0	<20.0 (TDF: < 4.0)	< 0.50	<0.60 (TDF: < 2.0)	<1.20	<2.0	<200.0	<2.0	<30.0
II	6,500 ~ 5,500			0.50 ~ 1.00						
III	5,500 ~ 4,500			1.00 ~ 1.50						
IV	4,500 ~ 5,500			1.50 ~ 2.00						

*Low heating value of RPF (refuse plastic fuel) and TDF (tire derived fuel) should be equal to or higher than 6,000 kcal/kg.

as potential fuel or energy resources, the authors found the followings:

The sewage sludge immersed or dipped into the melted PE solution greatly reduced water content and simultaneously increased heating value with increasing time for reaction such as coating or impregnation. The sewage sludge reacted for 15 mins in the melted PE solution reached water content of 6.7 wt% and heating value of 8,172 kcal/kg, which can satisfy the basic requirements of the class I criteria concerning solid refuse or derived fuel in Korea. The sewage sludge coated or impregnated with polyethylene can have a high feasibility to be utilized as potential fuel resources.

Acknowledgements

This research was supported by a grant (code 08 RTI B-03) from Regional Technology Innovation Program funded by Ministry of Land Transport & Maritime Affairs of Korean government. The authors appreciate the funding.

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