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Recycling Energy from Mixture of Sewage Sludge and Petroleum Coke Waste

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The disposal of sewage sludge using landfills and ocean dumping is no longer a viable option due to land scarcity and increasingly stringent environmental control regulations. As such, various efforts have been made to develop new sewage sludge recycling technologies. This work investigates the fundamental physical and chemical characteristics of rural type sewage sludge from Chungnam province in South Korea. The average moisture content, ignition loss, elementary analysis, and average heating value of the sewage sludge samples were examined. The average moisture content of the dewatered sludge was about 80%, while the organic matter was about 50% of the total solid sludge weight. The average heating value of a sewage sludge and petroleum coke waste mixture(1:1 weight ratio) was about 5,000 kcal/kg, thereby indicating a high potential for energy recycling.

Key words : sewage sludge, petroleum coke waste, recycling energy

1. Introduction

In Korea, the increased sewage sludge production from municipal wastewater treatment plants has created a serious environmental problem because about 90 % of gross domestic sewage sludge is disposed in landfills or by ocean dumping. However, these disposal methods are no longer viable due to more restrictions and higher costs. In Japan, the expense for municipal solid waste (MSW) handling and disposal averaged 46,280 ¥/t of landfill waste in 1993.[1] Therefore, emphasis has been placed on reducing MSW and incineration has become the predominant pretreatment practice. As a result, approximately 74 % of all MSW in Japan is combusted in about 1,854 plants with a total capacity of 178,106 t/d. In Germany, approximately 60 % of sewage sludge is disposed of in landfills, approximately 20~25 % used for agricultural purposes, 10% incinerated, and 3~4 % used for making compost.[2] In the future, it is expected that landfill disposal will also significantly decrease in Germany, while agricultural use and incineration increase.

Thus, one of the most urgent problems is the identification of an efficient sludge disposal method. Among the various disposal methods for sewage sludge, the incineration method is believed to be a promising candidate due to its ability to reduce volume, stabilize and recycle as a resource.[3] In addition, incineration is a possible means of converting bulky sludge into practically inert, odorless, and sterile ash. The incinerated ash and sintering pellet from sewage sludge can then be reutilized as building bricks, lightweight aggregates, cementitious material, and as a road base.[4~8] However, this method is costly(for example, 5,000 ~60,000 ¥/t in Japan[1]) in its use of fuel for the combustor operation when considering the reduction in sludge volume and utilization of sludge. Accordingly, incineration plants are needed that operate in an environmentally friendly mode, including flue gas emission control equipment that adheres to requirements, while also applying cost efficient technologies, such as the use of alternative fuel in parallel with conventional fuel. In addition, a more efficient energy recovery system should include the co-generation of electricity and heat. As such, the present study investigated alternative fuel characteristics for the incineration of sewage sludge, including energy utilization.

2. Experimental

The samples used in the experiment were obtained from rural type sewage treatment plants in the Chungnam region of South Korea. The samples were homogenized using a mortar and pestle. The petroleum coke wastes were obtained from Hae-Am Environmental Safety Co. The organic elements of the sewage sludge were analyzed using an elemental analyzer(EA 1108, CARLO ERBA Ins., Italy). Thermogravimetric analysis(TGA) and a differential thermal analysis (DTA) was carried out using a STA 409 thermal analyzer under an ambient atmosphere(Netzsch, Germany). The calorific values of the sewage sludge, petroleum cokes, and mixing samples were analyzed by an automatic calorimeter(LECO-250 AC-300, LECO Corp., USA).

The analysis of the heating values from sewage sludge used the following three model calorific equations.[9)]

1) Dulong eq.

HHV(kcal/kg)=8100(C)+34000[H-(O)/8]+2250(S)

2) Scheurer-Kestner eq.

HHV(kcal/kg)=8100[(C)- 3/4(O)]+34000(H)+2250(S)+5700[3/4(O)]

3) Steuer eq.

HHV(kcal/kg)=8100[(C)- 3/8(O)]+34000[(H)-1/16(O)]+2250(S)+5700[3/8(O)]

Where (C), (H), (O), and (S) are the weight percentages of carbon, hydrogen, oxygen and sulfur, respectively, and HHV means a high heating value.

Table 1. Contents of sludge obtained from sewage treatment plants in Chungnam region of South Korea[5)]

Sample	T-C(%)	H(%)	O(%)	T-N(%)	S(%)
A	73.2	11.1	2.0	11.4	2.3
B	72.8	10.7	3.2	11.5	1.8
C	51.7	7.7	31.4	7.9	1.3
D	60.0	9.3	18.3	10.1	2.3
E	59.1	8.8	21.5	8.4	2.2
Ave.	63.4	9.5	15.3	9.9	1.9

3. Results and Discussion

The average moisture content of the rural type sewage sludge was about 80 % and the organic matter was about 50 % of the total solid sludge weight. The proper and stable incineration of sewage sludge involving a high moisture content is still an unsolved problem.

Fortunately, a high organic matter content is good condition for incineration. Table 1 shows the organic element analysis data for the sewage sludge. Since the total hydrocarbon content was found to be relatively very high, the sewage sludge could be classified as a waste with a significant calorific value. The three model calorific equations were then applied to the elemental analysis data to obtain the characteristics of the sewage sludge heating values. Since the waste material contained many complicated compositions, corrections for the chemical components of each element were also applied to the heating value that was assumed based on the weight composition resulting from the elemental analysis data. According to the model

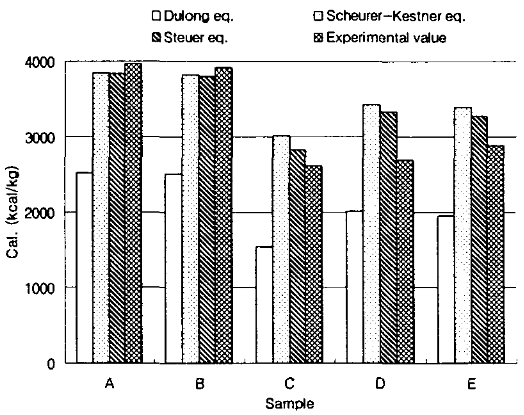

Fig. 1. Comparison of heat contents determined by calorimetric method and three model calorific equations using elemental analysis data.

equations applied, the assumed value in terms of the element components can be influenced by the composition of the element, the oxidation state, such as -COOH, -COH, -COO et al., and the chemical binding energy of carbon. The resulting data was then compared with the experimental values determined by a calorimeter, as shown in Figure 1. The experimental results were found to agree with those obtained using Steuer's eq., which originates from the assumption that half of the total oxygen in sewage sludge exists as crystallized water while the other half exists as CO due to incomplete combustion.[9] This theory was confirmed by the simultaneous TGA-DTA curves shown in Figure 2. The TGA curve showed three distinct weight losses at around 110, 370, and 900 ℃, respectively. The first endothermic peak at about 110 ℃ was due to the dehydration of the sewage sludge. The second strong exothermal peak was obtained at about 370 ℃. Above 370 ℃, the TGA curve showed a rapid weight decrease, indicating the combustion of the organic materials from the sewage sludge, which was about 50 % of the total sludge weight. The last exothermal peak was attributed to the transformation of the mineral matter. Accordingly, on the basis of the thermal analysis data, incinerated ash was obtained from the sewage sludge at 850 ℃.

If incineration is inevitable for the disposal of sludge, the first step in setting up an incineration plant is to analyze the existing incineration technologies and decide which technology is most

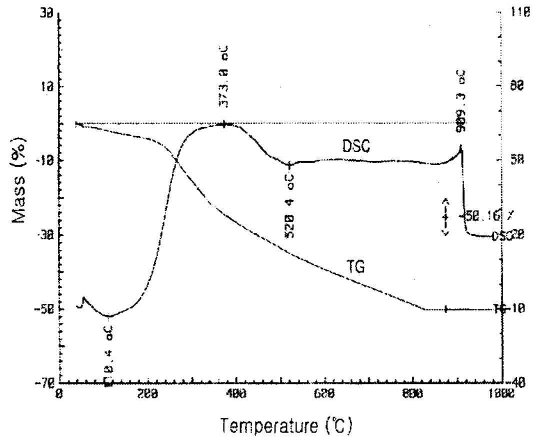

Fig. 2. TGA-DTA curves of sludge obtained from sewage treatment plants in Chungnam region of South Korea.

suitable with respect to the given requirements. These requirements include the scale of incineration, dry or wet levels, and whether the sludge has a high or low calorific value. As such, investigating the combustion process of sludge with a high moisture content is crucial when designing a plant. The solid residues from sludge incineration include air pollution control residues and bottom ash, while the rest is converted into gaseous compounds and released into the atmosphere. Therefore, an incineration plant also has to be equipped with a flue gas cleaning system to reduce emissions of CO, CO_2, NO_2, unburned hydrocarbons, SOx, HCl, and dioxins. Furthermore, for sewage sludge with a very high moisture content, a high preheating temperature is required for the combustion air in order to dry the sludge efficiently. Consequently, since such a system will inevitably involve high fuel costs, the possibility of an alternative fuel was investigated.

Accordingly, the heating values of just the sewage sludge were first identified and found to be 2,000~3,500 kcal/kg on a dry basis, which is well below the standard value of solid fuel, such as 4,400 kcal/kg for coal.[10] Next, methods for converting the sludge into fuel and the utilization of the ash as a functional construction material were considered. As regards the former, petroleum coke waste, a by-product from oil companies, was investigated. Petroleum coke waste is already being used by some cement plants. Table 2 shows the heating values according to the mixing ratio of the sludge and petroleum coke waste. The heating values were more than 5,000 kcal/kg when the percentage of petroleum coke waste in the mixture was above 50. This indicates that a mixture of sludge and coke can be suitable as an alternative fuel. In particular, a fluidized-bed incinerator[11] can facilitate the development of technology using sewage sludge and petroleum coke waste. This type of incinerator is fully instrumented with computer-controlled data acquisition system capabilities for collecting and displaying detailed operating information, including the temperatures and pressures throughout the system and flue gas concentrations. In addition, critical operational parameters, such as the excess air, superficial gas velocity, and fuel feed rate, can be continuously calculated and

Table 2. Calorific values and weight loss due to mixing ratio of sewage sludge and petroleum coke.

Sample	Mixing ratio (%)		Calorie (kcal/kg)	Weight loss(%)
	Sewage Sludge	Petroleum Coke		
C-10	0	100	8,547	98.24
C-11	10	90	7,913	93.00
C-12	20	80	7,346	91.57
C-13	30	70	6,727	84.71
C-14	40	60	6,082	88.54
C-15	50	50	5,459	72.50
C-16	60	40	4,844	68.37
C-17	70	30	4,214	67.71
C-18	80	20	3,593	59.38
C-19	90	10	3,039	54.51
C-20	100	0	2,383	51.26

displayed. Flue gas analyzers measure the concentrations of oxygen, carbon dioxide, carbon monoxide, nitrous oxides, sulfur dioxide, and total hydrocarbons. Therefore, the mixing of sewage sludge and petroleum coke waste for energy utilization would appear to be a useful strategy for the disposal of sludge with a high moisture content.

4. Conclusions

The physical and chemical characteristics of rural type sewage sludge were investigated.

1. The average moisture content was about 80 % and the organic matter was about 50 % of the total solid sludge weight.

2. The heating values were more than 5,000 kcal/kg when the mixing ratio of petroleum coke waste was above 50%. This indicates that a mixture of sludge and coke can be suitable as an alternative fuel. Further studies are necessary to determine the optimum plant operating conditions.

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