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Carbonization of Sewage Sludge for Using as Adsorbents

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In this study, optimum conditions of sewage sludge carbonization for adsorbent production and qualities of carbonized sewage sludge as an adsorbents were discussed. In order to study the characteristics on digestion and surplus sewage sludge, proximate analysis (such as moisture, ash, combustibles, volatile matter and fixed carbon content), elemental analysis and calorific value analysis of wet sewage sludge were performed and dried. For the carbonized sewage sludge obtained through the change of carbonization conditions, BET, pore size and iodine adsorption performance tests were carried out to derive the optimum conditions of carbonization. As a result of the overall review on the fixed carbon content of dried sewage sludge and specific surface area (BET), pore size and iodine adsorption performance of carbonized sewage sludge obtained. It is difficult to produce the adsorbent with good adsorption performance, but low-quality adsorbent is regarded to be possible. In spite of disadvantages, in the view of the carbonization of the sewage sludge to produce an adsorbent, the optimum carbonization temperature was derived to be 350-450 °C and the optimum carbonization time to be 30-60 min.

Keywords: Sewage sludge, Carbonization, Adsorbent, Specific surface area, Iodine adsorption.

INTRODUCTION

The world is currently facing a large economic and environmental crisis due to the high price of oil and global warming due to the depletion of fossil fuel resources. In these global economic and environmental crises, good energy is defined as the sustainable driving force for national development. Thus, a new and sustainable, competitive and renewable energy policy is strongly promoted.

Studies related to the treatment and recycling of the sewage sludge generated in the sewage treatment process have progressed steadily, but it is regarded that a distinct technology has not yet been revealed. In particular, recycling of the sewage sludge through drying and carbonization has the advantages of enabling comparatively wide utilization and that treatment is easy for each purpose. However, from the perspective that equal quality assurance and utilization method of the product are not developed sufficiently. It is evaluated that the reliability and the stability of the technology is still insufficient and currently still in the development stage.

There are number of studies for producing adsorbents from sewage sludge, but there is still not sufficient data in our opinion [1-4]. Moreover, the results have differentiated content that would be difficult for general application. Park *et al.* [1] reported that the maximum iodine adsorption was 123.5 mg/g with the carbonized sewage sludge obtained for 30 min at 700 °C and 50 % decolorization in the wastewater treatment was achieved when carbonizing for 15 min at 700 °C as a optimum carbonization condition in the basic study result for utilizing carbonized sewage sludge as the absorbent. Dong-Hyun *et al.* [4] reported differently that the optimum sewage sludge carbonization condition with a dried sewage sludge of 0.25-0.5 mm diameter and moisture content of 10 % is a carbonization temperature at 600 °C, resulted in a maximum iodine absorption of 149.1 mg/g and yield of 30.9 %. And also, for the specific surface area, the carbonized sewage sludge increased greatly to 62.31 m^2/g compared to the 6.44 m^2/g of the dried sewage sludge and the pore distribution of the carbonized sewage sludge was reported to be 20-100 Å and that the medium pore of 36.61 Å mainly developed for the average pore diameter. Therefore, in this study, re-examination was performed on the currently ambiguous state of optimum carbonization conditions for the sewage sludge absorbent production to clearly define this matter. The qualities of carbonized sewage sludge as an adsorbents were also discussed.

EXPERIMENTAL

Used sewage sludge and subject facility: The samples used in the experiment are dewatered sewage sludge generated by treating the domestic sewage in Daejeon City, Korea through the standard activated sludge method. After collecting the samples, they were dried to minimize the change in properties. For the drying condition, the samples were completely dried for 6 h at 105 °C and the dried samples were sealed and cold stored for analysis.

Analysis of the sewage sludge: Approximate analysis and elemental analysis were carried out to review the basic characteristics of the sewage sludge. Also, after carbonization, BET specific surface area was measured and iodine absorption test were performed to review the usability as the absorbent. But activation of carbonized sewage sludge with steam or any chemicals did not carried out.

Carbonization equipment and process: The equipment used for carbonization in this study included carbonizing furnace, temperature measurement equipment and nitrogen gas supplying equipment as shown in Fig. 1.

In the carbonization process, the samples were fully dried and fine grinded for the production of high quality absorbent, because a great amount of moisture in the sewage sludge can reduce the hardness. The dewatered sewage sludge was dried up to 10 % of moisture content in the electric furnace at 105 °C, grinded and sieved with a diameter of 0.25-0.5 mm for usage.

Before the carbonization process was performed, the inside of the carbonization reactor was replaced into inert atmosphere with the N_2 gas flow at 100 mL/min and preheated to the constant carbonization temperature. When the carbonization temperature was reached, stabilization time was provided to maintain a constant inner temperature.

After that the inside of the carbonization reactor was stabilized, the dried sewage sludge was inserted as the carbonizing sample was carbonized for 60 min at each carbonizing temperature. Here, the carbonizing temperature was changed from 250 to 650 °C to continue the test. Also, in the optimum carbonizing temperature derived, the carbonizing was changed at 20, 40, 60, 80, 100 and 120 min to review the effect according to carbonization time variation. To maintain the reducing atmosphere of the carbonization process, N_2 gas at 100 mL/min was injected continuously.

RESULTS AND DISCUSSION

Analysis of physico-chemical properties of excess and digested sewage sludge: The results of analysis on physico-chemical properties of excess and digested sewage sludge discharged by the sewage treatment plant in D City are shown as follows:

Proximate analysis

Moisture, combustibles and ash analysis: The moisture, ash, combustibles content of wet sewage sludge were analyzed according to the ASTM [5-7] and the results of analyzing are shown in Table-1. In case of the excess sludge, moisture content was approximately 77-80 %, ash content about 3-6.5 % and combustibles 16-17 %. In case of the digested sludge, moisture content was approximately 79-82.5 %, ash content about 6-9 % and the combustibles 11-13 %.

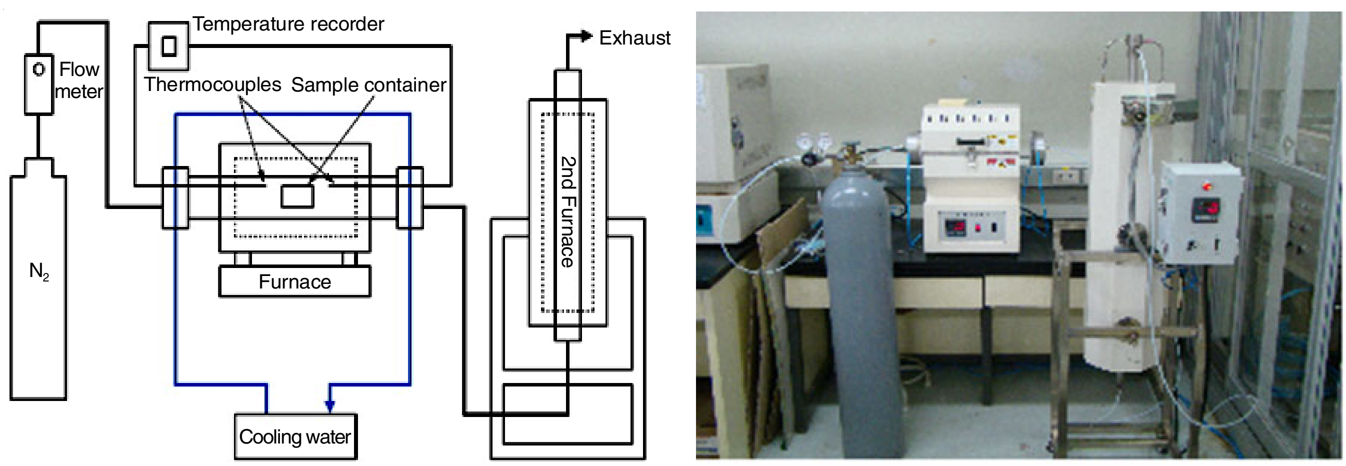

Fig. 1. Schematic diagram and image of the carbonization equipment for the sewage sludge

TABLE-1
MOISTURE, ASH, COMBUSTIBLES CONTENT OF WET SEWAGE SLUDGE

Month	Excess sludge				Digested sludge			
	Moisture	Ash	Combustibles	Sum	Moisture	Ash	Combustibles	Sum
Feb.	80.05	3.03	16.92	100.00	82.39	5.95	11.66	100.00
Mar.	78.78	4.68	16.54	100.00	80.12	7.16	12.72	100.00
Apr.	78.39	4.68	16.93	100.00	82.37	5.68	11.95	100.00
May	77.64	6.47	15.89	100.00	81.12	7.44	11.44	100.00
Jun.	77.57	5.96	16.47	100.00	78.58	8.76	12.66	100.00
Jul.	68.66	17.21	14.30	100.00	66.47	20.63	13.71	100.00
Aug.	66.72	18.85	14.43	100.00	63.33	22.09	14.56	100.00
Oct.	78.63	5.82	15.54	100.00	70.34	13.23	16.38	100.00
Average	75.81	8.34	15.88	100.00	75.59	11.37	13.14	100.00

TABLE-2
VOLATILE MATTER AND FIXED CARBON ANALYSIS RESULTS OF THE WET SEWAGE SLUDGE

Month	Excess sludge			Digested sludge		
	Volatile matter	Fixed carbon	Sum	Volatile matter	Fixed carbon	Sum
Feb.	12.17	4.75	16.92	8.79	3.10	11.89
Mar.	12.28	4.21	16.49	9.31	3.41	12.72
Apr.	12.87	3.78	16.65	8.57	8.05	16.62
May	12.66	2.97	15.63	8.65	2.64	11.29
Jun.	12.21	4.27	16.48	9.14	3.59	12.73
Jul.	12.44	1.86	14.30	12.41	1.31	13.72
Aug.	14.24	0.19	14.43	14.32	0.24	14.56
Oct.	15.42	0.12	15.54	16.28	0.10	16.38
Average	13.04	2.77	15.81	10.93	2.81	13.74

Analysis of the volatile matter and fixed carbon: The analytical results of the volatile matter (VM) and fixed carbon (FC) of wet excess and digested sewage sludges are shown in Table-2. As the results of analyzing the volatile matter and the fixed carbon [8], the fixed carbon was approximately 3-5 % for the excess sludge and 2.5-3.5 % for the digested sludge.

Considering this amount of fixed carbon content, it specifies that carbonizing the wet excess and digested sewage sludges to produce the adsorbent is realistically difficult. Therefore, the carbonized sewage sludge obtained is considered to be possible for use as soil conditioner. Additionally, if it is dried properly without loss in the volatile matter, it is considered to be possible for use as a fuel due to the sufficient volatile matter in dried state. It can be seen during calorific value analysis.

Elemental analysis: The elemental analysis results for combustibles of the dried excess and digested sewage sludge are shown in Figs. 2 and 3. As the results of the elemental analysis, the elemental composition ratio of combustibles in the excess sludge was higher than that in the digested sludge except for sulfur.

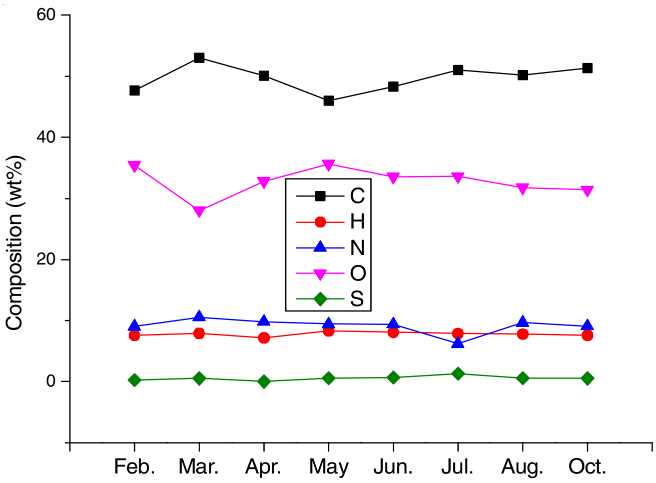

Fig. 2. Elemental analysis results for combustibles of the dried excess sewage sludge

In case of the dried excess sludge, carbon was average 49.75 %, oxygen was average 32.69 %, nitrogen was average 9.13 %, hydrogen was average 7.7 % and sulfur was average 0.54 %. Otherwise, in the case of the dried digested sludge, carbon was average 49.75 %, oxygen was average 32.69 %, nitrogen was average 9.13 %, hydrogen was average 7.7 % and sulfur was average 0.54 %.

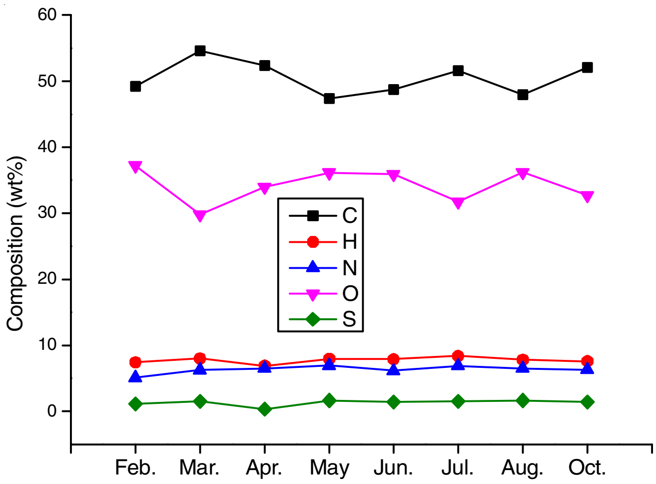

Fig. 3. Elemental analysis results for combustibles of the dried digested sewage sludge

Calorific value analysis: The calorific values of the dried excess and digested sewage sludges were measured by using the bomb adiabatic calorimeter and calculated by using Dulong, Scheurer-Kestner and Steuer equations shown in Figs. 4 and 5. The calorific value of the dried excess sludge by using calorimeter was approximately 3,300-4,400 kcal/kg for Feb. to Jun, but the calorific values for July and August were too low in the range of 2,200-2,400 kcal/kg, due to be mixed it with soil *etc.* in raining season. This results are in line with proximate analytical results.

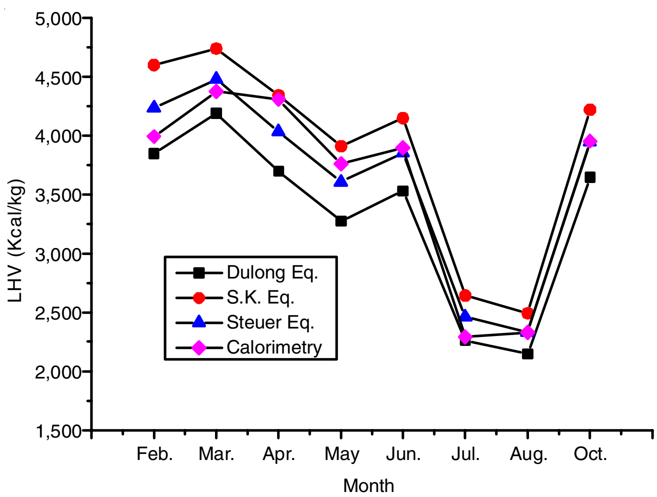

Fig. 4. Calorific value for the dried excess sewage sludge

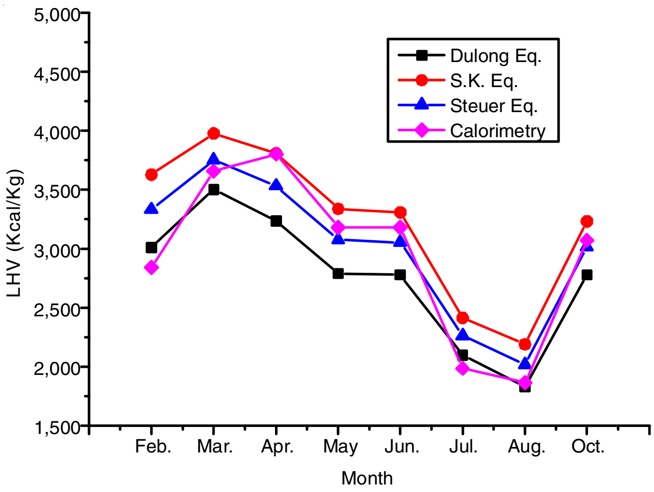

Fig. 5. Calorific value for the dried digested sewage sludge

The calorific value of the dried digested sludge by using calorimeter was approximately 2,800-3,800 kcal/kg for Feb. to Jun, but the calorific values for July and August were also too low in the range of 1,800-2,000 kcal/kg.

The calorific values measured by using bomb adiabatic calorimeter and calculated by using Scheurer-Kestner and Steuer equations are similar each other, but The calorific values calculated by using Dulong equation is lower of approximately 500-800 kcal than their values.

Analysis of physicochemical properties of carbonized excess and digested sewage sludge

BET specific surface area analysis: As the results of measuring the BET specific surface area of carbonized excess and digested sewage sludge [8], the specific surface area of the carbonized sewage sludge increased according to the increase in the carbonization temperature and the maximum values were obtained with a carbonization time of 30-60 min at more than 450 °C (Fig. 6). BET specific surface area of the carbonized sewage sludge was approximately 10-16 m^2/g compared to the approximately 3-5 m^2/g of the dried sewage sludge, but less than 62.31 m^2/g by Dong-Hyun *et al.* [4]. The BET specific surface area of commercial activated carbon is in the range of 800-1,200 m^2/g for water purification.

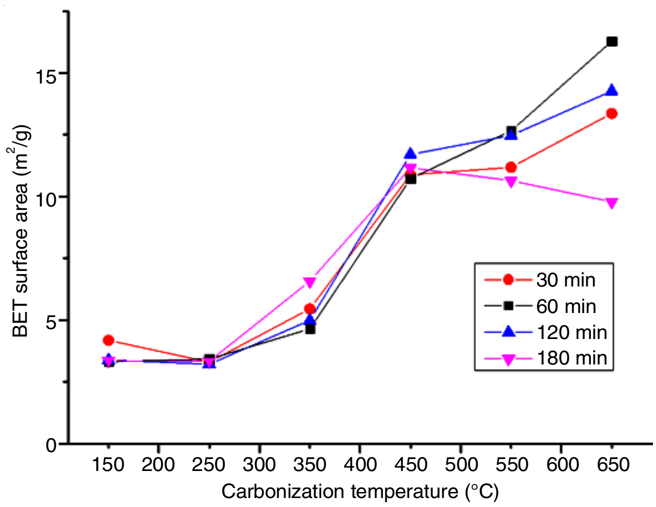

Fig. 6. BET specific surface area characteristics of carbonized excess sludge according to change in carbonization condition

Pore size analysis: The average pore size of carbonized excess and digested sewage sludges were the largest of approximately 30-35 Å at 250 °C and decreased according to the increase in the carbonization temperature (Fig. 7). There was almost no effect according to the carbonization time. Average pore size of the carbonized sewage sludge obtained from 450 °C was approximately 17 Å compared to the approximately 23-27 Å of the dried sewage sludge, but less than approximately 36.61 Å by Dong-Hyun *et al.* [4]. The average pore size of commercial activated carbon is in the range of 17-20 Å for water purification.

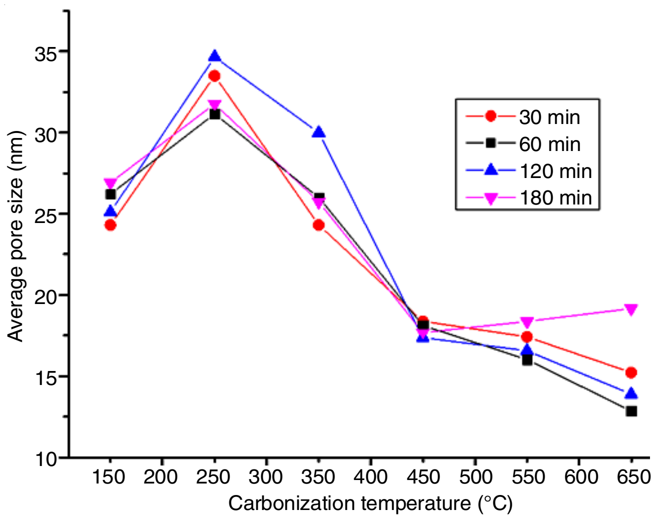

Fig. 7. Average pore size of the excess sludge carbide according to the change in carbonization condition

Iodine adsorption performance tests: One of the measurement methods of evaluating the adsorbents are based on the iodine adsorption; therefore, the iodine adsorption performance of the carbonized excess and digested sewage sludge were reviewed according to the change in the carbonization condition. As the results of the iodine adsorption performance test of the carbonized excess sludge and the digested sludge, the optimum carbonization temperature were 350-450 °C and the optimum carbonization time was 30-60 min.

As shown in Figs. 8 and 9, in case of carbonized excess sewage sludge, iodine adsorption performance of the carbonized sewage sludge obtained from 350 °C were approximately 180-240 mg/g compared to the approximately 110-160 mg/g of the dried sewage sludge at 150 °C, but it is higher than approximately 149 mg/g by Dong-Hyun *et al.* [4]. The iodine adsorption performance of commercial activated carbon is approximately 1,000 mg/g for water purification.

In case of the carbonized digested sewage sludge, iodine adsorption performance of the carbonized sewage sludge obtained from 350 °C were approximately 160-175 mg/g compared to the approximately 110-140 mg/g of the dried sewage sludge at 150 °C, but it is almost similar to approximately 149 mg/g by Dong-Hyun *et al.* [4].

Optimum carbonization condition for preparing absorbents: As the results of reviewing the BET specific surface area, pore size and the iodine adsorption performance test of the carbonized excess and digested sewage sludge obtained according to the change in the carbonization condition, the

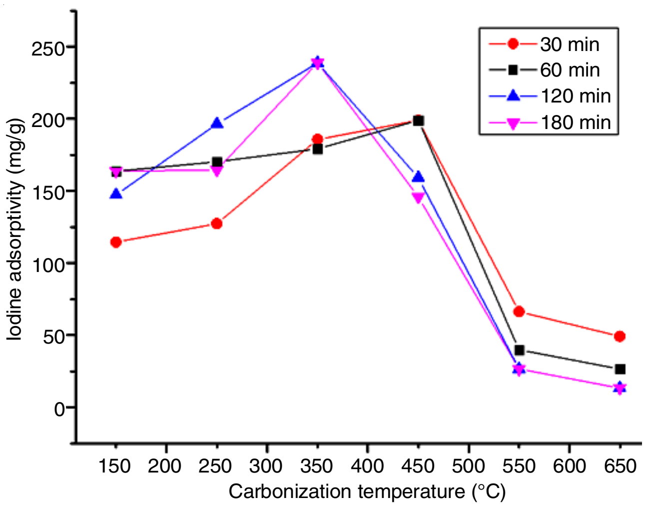

Fig. 8. Iodine adsorption performance test results of carbonized excess sewage sludge according to change in carbonization condition

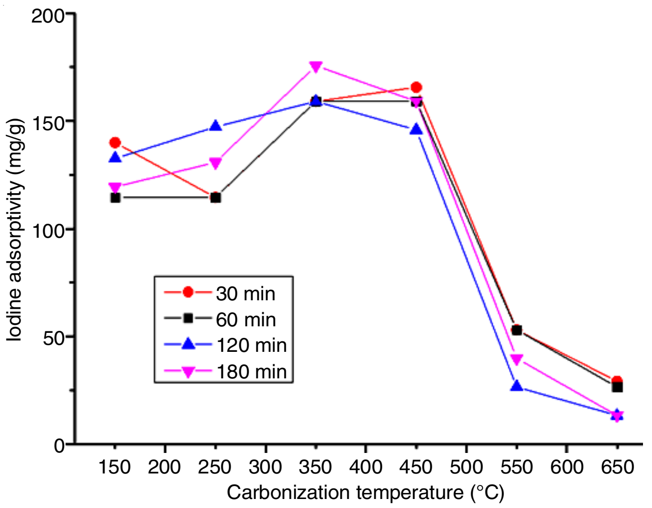

Fig. 9. Iodine adsorption performance test results of carbonized digested sewage sludge according to change in carbonization condition

optimum carbonization temperature was 350-450 °C and the optimum carbonization time was derived in the range of 30-60 min, when using the sewage sludge as the raw material for adsorbent production.

Conclusions

In the study of using sewage sludge to derive the optimum carbonization conditions for producing carbonized sewage sludge with absorption possibility, the results were obtained as shown below:

• For the excess sludge, moisture was approximately 77-80 %, ash content about 3-6.5 % and the combustible was 16-17 %. For the digested sludge, moisture was approximately 79-82.5 %, ash content about 6-9 % and combustible 11-13 %.

• The fixed carbon was approximately 3-5 % for excess sludge and 2.5-3.5 % for the digested sludge. Considering this amounts of fixed carbon content, it specifies that the carbonization of the wet excess and digested sewage sludges to produce the adsorbent is realistically difficult. Therefore, the carbonized sewage sludge obtained is considered to be possible for use as soil conditioner. Additionally, if it is dried properly without loss in the volatile matter, it is considered to be possible for use as a fuel due to the sufficient volatile matter in dried

• The calorific values of the dried excess sewage sludge was approximately 3,800-4,400 kcal/kg and the dried digested sewage sludge was about 2,800-3,800 kcal/kg. The calorific value of the excess sludge was approximately 500-1,000 kcal higher per kg compared to the digested sludge.

• BET specific surface area of carbonized sewage sludge increased as the carbonization temperature increased and the maximum values were obtained at 30-60 min of carbonization time at temperature of more than 450 °C. BET specific surface area of the carbonized sewage sludge was approximately 10-16 m^2/g compared to the approximately 3-5 m^2/g of the dried sewage sludge.

• The average pore size of carbonized sewage sludge was the largest of approximately 30-35 Å at 250 °C and decreased according to the increase in the carbonization temperature. Average pore size of the carbonized sewage sludge obtained from 450 °C was approximately 17 Å compared to the approximately 23-27 Å of the dried sewage sludge.

• Iodine adsorption performance of the carbonized excess sewage sludge obtained from 350 °C were approximately 180-240 mg/g compared to the approximately 110-160 mg/g of the dried sewage sludge.

• As the results of reviewing the BET specific surface area, pore size and the iodine adsorption performance test of the carbonized excess and digested sewage sludge, the optimum carbonization temperature was 350-450 °C and the optimum carbonization time was derived in the range of 30-60 min, when using the sewage sludge as the raw material for adsorbent production.

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