

Characteristics of Spontaneous Combustion of Various Fuels for Coal-Fired Power Plant by Carbonization Rank

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Abstract

Spontaneous combustion propensity of various coals of carbonization grade as a pulverized fuel of coal-fired power plant has been tested from an initial temperature of 25°C to 600°C by heating in an oven with air to analyze the self-oxidation starting temperature. These tests produce CPT (Cross Point Temperature), IT (Ignition temperature), and CPS (Cross Point Slope) calculated as the slope of time taken for a rapid exothermic oxidation reaction at CPT base. CPS shows a carbonization rank dependence whereby wood pellet has the highest propensity to spontaneous combustion of 20.995 °C/min. A sub-bituminous KIDECO coal shows a CPS value of 15.370 °C/min, whereas pet coke has the highest carbonization rank at 2.950 °C/min. The nature of this trend is most likely attributable to a concentration of volatile matter and oxygen functional groups of coal surface that governs the available component for oxidation, as well as surface area of fuel char, and constant pressure molar heat.

Keywords: Carbonization Rank, CPT, Cross Point Temperature, IT, Ignition Temperature, CPS, Cross Point Slope, Oxygen Functional Group

I. INTRODUCTION

To be used as a power generating fuel in both domestic and international pulverized coal power plant, it is necessary to predict and manage the spontaneous ignition and the possibility of fire in the storing and pulverizing process. The domestic 500 MW standard coal power plants typically unload the imported coal into their own facility and store them up to three months. Depending on the conditions and types of the coal, spontaneous combustion happens in various ways. According to a study of the spontaneous ignition occurring in the coal-fired power plant in the recent five years, it was found that spontaneous ignition occurred in more than 50% of the imported coal [1]. Fig. 1(a) shows a picture of a spontaneous combustion occurring on coal stockpile at the domestic standard coal power plant coal depot, which causes problems, such as (1) deterioration of working environment from toxic gas, (2) the loss of intrinsic caloric value of coal, (3) combustion failure caused by the water used in extinguishing the fire and the cost, and (4) incomplete combustion due to change in the properties of the coal.

Unlike coal depot, power generating fuel handling process requires the first injection of air at temperatures of 200 to 300°C at either roller mill or ball mill, in order to cause combustion at the boiler. Devolatilization often causes spontaneous combustion. Fig. 1(b) shows the fire scene with the coal pulverizer during the pulverizing process. When a fire occurs in the coal pulverizing stage at a power plant, a sudden break in the pulverizing process causes an output cutback. Therefore, this paper investigated the characteristics of spontaneous ignition with respect to the carbonization rate of the fuel used in coal power plants, as well as the correlation to the physical properties.

II. CONSIDERATION OF RELATED THEORIES

As shown in Fig. 2(a), the spontaneous ignition of a solid material occurs when a heat source, either internally or externally, is applied to a sample, which causes the temperature to rise. The exothermic reaction (oxidation,

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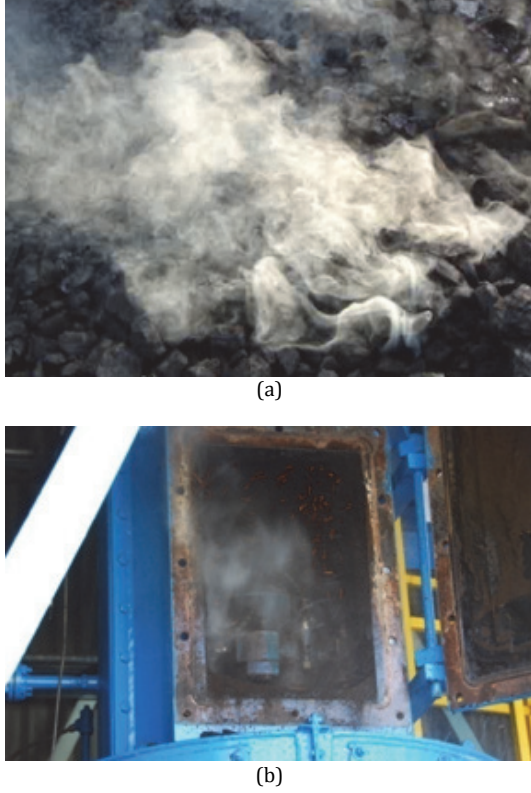


Fig. 1. Real view of spontaneous combustion at (a) Coal stockpile and (b) Pulverizer of coal fired power plant.

conduction, convection, radiation, or endothermic) generates ignition gas on the surface exposed to the air, and the mixing of the gas and air causes the oxidation.

The Semenov Theory of Ignition [2] considers coal oxidation as one overarching reaction and states that if the exothermic heat generation rate from the oxidation reaction between oxygen in the coal and air is larger than the rate at which the exothermic reaction heat is lost around the reaction, the heat is accumulated and eventually ignited.

$$Q_G(T_i) = Q_L(T_i) \quad (1)$$

$$k_o \exp \frac{E}{RT_i} A \Delta H_C = hA(T_p - T_G) + \sigma \varepsilon A(T_p^4 - T_G^4) \quad (2)$$

Equation (1) is the thermal equilibrium equation describing the heat generation caused by the surface oxidation and the heat loss to the surroundings, while Equation (2) states that the heat generated by the coal is the sum of the enthalpy of the reaction and calorific value and the heat loss is the sum of convection and radiation heat transfer.

$$\left(\frac{dQ_G}{dT} \right)_{T_i} = \left(\frac{dQ_L}{dT} \right)_{T_i} \quad (3)$$

$$\frac{Ek_o z_{O_2}^n \Delta H_C}{RT_i^2} \exp \frac{E}{RT_i} = \frac{2\lambda}{d_p} + 4Q\varepsilon T_i^4 \quad (4)$$

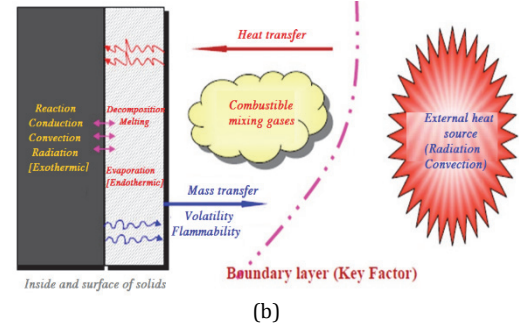
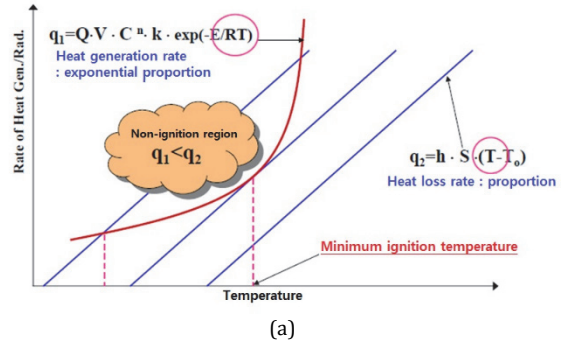


Fig. 2. Mechanism of spontaneous combustion. (1) Rate of heat generation and radiation. (2) Diagram of spontaneous combustion

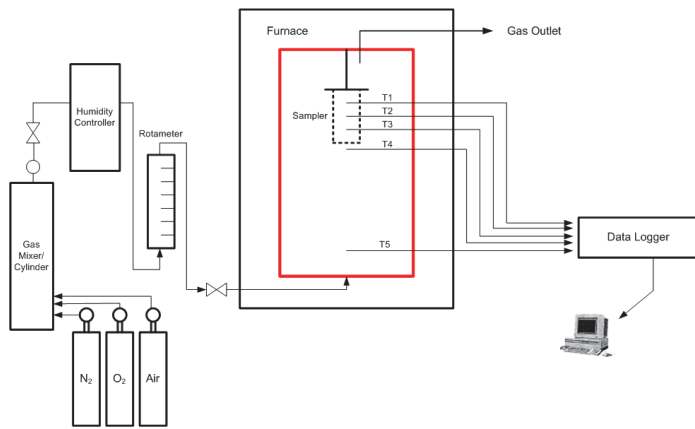
In order to calculate the ignition temperature of the coal in Equation (3), the temperature change with respect to the exothermic reaction rate and the heat loss rate around the reaction are differentiated by the temperature function. The chemical reaction at the surface of the coal and the diffusion into the coal pores must be considered at the same time, and the oxygen concentration in the air (Z_{O_2}) is 0.21. The activation energy can be derived from Equation (6) by linear regression analysis. The frequency factor in Equation (7) can be determined from the correlation analysis of activation energy and temperature.

$$B_i = T^2 \left(\frac{2\lambda}{d_p} + 4Q\varepsilon T_i^3 \right) \quad (5)$$

$$E = - \frac{\ln \left(\frac{B_i}{B_{ir}} \right)}{\frac{1}{R} \left(\frac{1}{T_i} - \frac{1}{T_{ir}} \right)} \quad (6)$$

$$k_o = \frac{RB_i}{Ek_o z_{O_2}^n \Delta H_C \exp \frac{E}{RT_i}} \quad (7)$$

In order for spontaneous ignition to occur on the surface of a solid material such as coal, there must be a minimum ignition energy, the least amount of energy required to initiate surface oxidation. This minimum ignition energy [3] is the energy of the ignition sources (ambient temperature, oxygen, chemical reaction, external heat, etc.) that ignites the gas



(a)



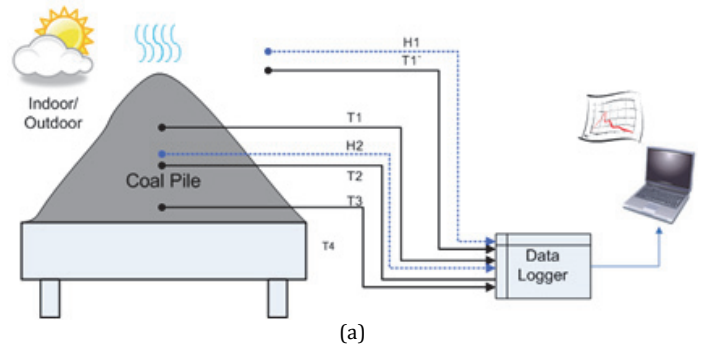
(b)



(c)

Fig. 3. (a) Diagram. (b) Real view of CPT tester. (c) Pt mesh sample holder

mixture of the flammable gas generated from the surface and the oxygen in the air. The minimum CPT (Cross Point Temperature) and IT (Ignition Temperature) depend on the physical and chemical properties of each material. Normally, the heat dissipation rate is linearly proportional to the temperature difference, but the actual heat dissipation rate is exponentially curved. The temperature at which the theoretical heat dissipation rate graph intersects with the actual heat dissipation rate graph is defined as the IT.



(a)



(b)

Fig. 4. (a) Diagram. (b) Real view of coal stockpile

III. MATERIAL AND METHOD

A. Test Method of CPT, IT and CPS

In the case of a coal-fired power plant, the high-temperature air of 200 to 265°C is injected into the pulverizer, indicating that the need for a temperature measurement method during the temperature rise test. Standard test methods for the temperature rise method exclude the use of explosive substances, such as coal-fired power generation fuels, which are in contact with air when exposed to room temperature according to NF T20-036 [4]. The purpose of the standard test method is to provide basic data on the ignitability of solid materials, which are useful for the basic ignition characteristics of solid materials and where spontaneous ignition occurs when the ambient temperature rises. The temperature rise test equipment is composed of a heating furnace, a hot wire, a thermometer, a temperature control device, a data recording device, and a measuring sample container, as shown in Fig. 3. In the heating furnace, four sets of heat lines were installed inside the furnace of the inner volume of 90 liter (45 cm × 45 cm × 45 cm) to keep the temperature distribution inside.

The circulation fan is installed in the exhaust port on the upper part of the heating furnace, and automatically operates when the inside temperature of the furnace is higher than the set temperature. Two Chromel-Alumel thermocouples with a diameter of 0.35 mm were used for the control of the ambient temperature in the furnace and for measuring the center temperature of the test samples. They were installed at the center of the furnace and the center of the test specimen,

Table 1

Samples	Proximate and ultimate analysis results of samples									
	HHV (MJ/kg, NAR)	Proximate analysis (wt%)					Ultimate analysis (wt%)			
	M	FC	VM	Ash	C	H	O	N	S	
Petcoke 0.6	35.82	0.76	83.75	13.79	0.55	93.35	4.02	1.25	0.34	0.49
Kyungdong C&A	12.72	3.31	44.46	7.70	44.53	84.93	4.75	9.56	0.52	0.24
KIDECO	29.50	5.01	55.45	32.77	6.77	78.57	5.07	15.2	0.99	0.16
Wood pellet	18.68	29.68	32.28	30.37	7.67	72.24	5.07	21.49	0.86	0.35

※ NAR: Net As Received

Table 2

Spontaneous combustion index of solid fuels by Idemitsu laboratory			
Rank	SCP	T180	SCI
A	difficulty	>115	<2
B	usual	85-115	2-4
C	caution	70-85	4-8
D	danger	50-70	8-20
E	sudden	<50	>20

※ SCP: Spontaneous combustion propensity

respectively. The temperature control program (Konics' EC-5600) that controls the temperature inside the furnace is a relay switch that adjusts the power (current) value of 8 heating wires of 1,000 W and is turned on and off in conjunction with the operation of the upper circulating fan. The temperature data is recorded at intervals of 5 seconds using an automatic recording device (Yokogawa Pen type recorder, Model 4151). The sample vessel was made by coating platinum on a 325-mesh stainless screen to smooth the contact of the reaction air with the cylindrical shape [5] and was used within the range that the pulverized coal did not pass through. The outer wall was insulated with about 10 cm asbestos. The actual shape of the sample container is shown in Fig. 3(c). To conduct the test, 50 g of the sample with passing size of 500-mesh sieve was placed inside the 325-mesh stainless steel screen, and the air was supplied at the rate of 30 cm³/min, while raising the temperature inside the electric furnace at the rate of 2 °C/min. The temperature was measured at both inside the electric furnace and at the center of the sample. When the air temperature inside the furnace and the core of the sample reaches equilibrium, reaction starts and it is called Cross Point Temperature (CPT). It is defined as CPT or the start of the Ignition Temperature (IT) where the ignition temperature is usually about 400°C when the flame is generated inside the electric furnace [4]. In addition, the spontaneous ignition tendency was investigated by analyzing the ignition temperature (CPT) and the ignition temperature rise rate (CPS), which is the slope of the exothermic temperature per hour at the ignition start temperature.

B. Experimental Method of Outdoor Coal Stockpile

In the case of outdoor, low-firing, spontaneous ignition

Table 3

Spontaneous combustion rank of samples by proximate and ultimate analysis results of samples							
Samples	Odaf	O/C	H/C	M	HHV	SCI	Rank
Petcoke 0.6	1.25	0.013	0.043	0.76	35.82	0.0005	A
Kyungdong C&A	9.56	0.113	0.056	3.31	12.72	0.0720	A
KIDECO	15.2	0.193	0.065	5.01	29.50	0.8553	A
Wood pellet	21.49	0.297	0.070	29.68	18.68	8.1820	C
	21.53	0.319	0.080	5.72	20.01	2.2270	B

Table 4

CPT, IT, and CPS of samples				
Samples	CPT (°C)	IT (°C)	CPS (°C/min)	Rank
Petcoke 0.6	231.8	259.8	10.571	
Kyungdong C&A	260.6	286.9	12.420	
KIDECO	225.8	253.9	12.516	
Wood pellet	236.1	284.3	15.370	Danger
	248.3	264.5	20.995	Sudden

simulation, as shown in Fig. 4, five power generation fuels are installed outdoors in a form similar to the low firing of a 500 MW standard coal-fired power plant. In the case of the coal depot simulations, 300 kg of 50 mm granular sized coal is piled up for monitoring, and the degree of heat accumulation, cooling, and ignition inside the coal is monitored according to the atmospheric temperature and humidity. The composition ratio of two Chromel-Alumel thermocouples was measured at a depth of 5 cm (T1), 50 cm (T2), and 1 m (T3) from the top surface.

C. Fuel Analysis

The industrial analysis for analyzing the volatile matter, fixed carbon, ash, and moisture of the fuel for power generation was analyzed by adhering to KS E3705 [6], and the elemental analysis, such as carbon, hydrogen, oxygen, nitrogen, and sulfur was analyzed with the KS E 3712 [7] method. The calorific value was analyzed with the KS E 3707 [8] method. The heat flux used for analyzing endothermic and exothermic reactions of power generation fuels was analyzed using DSC (Differential Scanning Calorimetry, Perkin Elmer, STA 8000/DSC 8000). The sample was placed in an aluminum pan, covered with a lid, sealed, and heated to 25°C to 600°C at a heating rate of 5 °C/min, using air or nitrogen as carrier gas. The absorption or emission energy (dΔQ/dt, W/g) was analyzed. The BET non-target, pore volume, and pore size of each power generating fuel sample were analyzed by dehydration and devolatilization of the proximate analysis [6], and 10 g of the remaining sample was removed for 1 hour at 150°C through vacuum using isothermal adsorption and desorption of nitrogen at 77K, following the air permeability apparatus (ASAP2010, Micromeritics Corp.). Heat transfer coefficients, such as thermal conductivity, specific thermal conductivity, and specific molecular heat (Cp) of the power generating fuel sample, were analyzed using a thermal diffusivity meter (Netzschlfa Analyzer, Netzsch Corp.) at 25°C in a nitrogen gas atmosphere. Hydrocarbon X-ray photoelectron spectroscopy (XPS) was performed using vacuum

generators (XPS, ANOVA, KRATOS Corp.) to study the distribution of couplers and oxygen functional groups.

IV. RESULT AND DISCUSSION

A. Carbonization

Table 1 shows the results of the heating value, proximate (moisture, volatile matter, fixed carbon, ash), and elemental analyses (carbon, hydrogen, oxygen, nitrogen, sulfur) of the power generating fuel samples, including petroleum coke (Pet-coke 0.6) with sulfur content of about 0.49%, a domestic anthracite coal called Kyung-dong coal, KIDECO coal from Hunter Valley Operation (HVO) mine operated by Australia CA (Coal & Allied Industries Limited), a bituminous coal produced in KIDECO Pasir mine in Indonesia, and wood pellet manufactured by KEPCO Industry Development. As shown in Table 1, the calorific value was 35.82 MJ/kg for Pet-coke 0.6, 29.50 MJ/kg for C&A and 20.01MJ/kg for wood pellets, and Kyung-dong anthracite coal was the lowest at 12.72 MJ/kg. As a result of the proximate analysis, the water content of KIDECO coal was 29.68%, and the moisture content of petroleum coke was 0.76%. In case of fixed carbon, which has the greatest effect on calorific value, petroleum coke is the highest at 83.75%, and the volatile matter content which has the greatest influence on the burning rate is the highest at 69.00% of wood pellet. In case of ash that has the greatest influence on the formation of clinker in the boiler, 44.53% of Kyung-dong anthracite coal was the highest.

On the other hand, the elemental analysis of carbon, which is an index of carbonization, showed that petroleum coke was the highest with 93.35%, followed by Kyungdong anthracite, C & A bituminous coal, KIDECO sub-bituminous coal and wood pellet. Table 1 shows the results of the analysis of the degree of carbonization of each sample. As shown in Fig. 5(a), petroleum coke and hard coal with high carbon content were the semi-anthracite coal grade, C&A coal was bituminous coal, KIDECO coal was bituminous coal grade, and wood pellet showed similar carbonization to peat. In addition, the volatile secretion and the fixed carbon ratio for the combustible material are shown in Fig. 5(b). The volatilization ratio of the wood pellets with the lowest carbonization was the highest, the fixed carbon ratio was the lowest, and the fixed carbon ratio of the petroleum coke having the highest carbonization was the highest.

B. Spontaneous Combustion Index (SCI)

The Idemitsu Institute of Japan [9] analyzed the spontaneous ignitability of coal (110°C after nitrogen preheating, and then measured the rise time up to 180°C by supplying pure oxygen). The following Spontaneous Combustion Index (SCI) has been proposed as a predictor of the correlation between the two.

$$SCI = \frac{H}{C} \times \left(\frac{O}{C} \times 100 \right)^2 \times \frac{M_{ad}[\%]}{1000} \times \frac{HHV_{ad}[\text{kcal/kg}]}{1000} \quad (8)$$

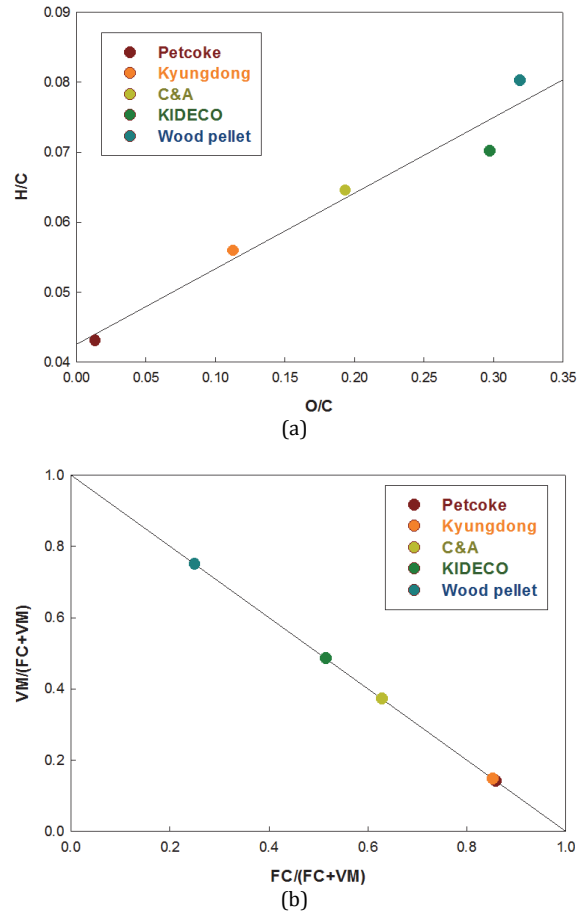


Fig. 5. (1) Carbonization rank. (2) combustible matter ratio of various samples.

As for the SCI, as shown in Table 2, a value of above 20 means eminent ignition (Rank E), 8-20 indicates danger, 4-8 indicates caution, 2-4 indicates normal, and below 2 (Rank A) indicates hard to ignite.

Therefore, as a result of the SCI index analysis according to the degree of carbonization, as shown in Table 3, petroleum coke is identified as the most ignited stable carbon with 0.0005, Kyung-dong anthracite at 0.0720, and C & A bituminous coal at 0.8553. However, the bituminous coal of KIDECO was at 8.1820, and the wood pellet showed normal range.

C. Ignition Temperature

As shown in Table 4 and Fig. 6, in the case of petroleum coke fuel's having a very high calorific value, the ignition-start temperature (CPT) was 231.8°C, and the ignition temperature (IT) was 259.8°C. On the other hand, Kyung-dong anthracite, with the highest degree of carbonization, had the highest ignition-start temperature, at 260.6°C and the highest ignition temperature, at 286.9°C. On the other hand, the wood pellet, having the highest volatile content ratio, has an ignition start temperature of 248.3°C and an ignition

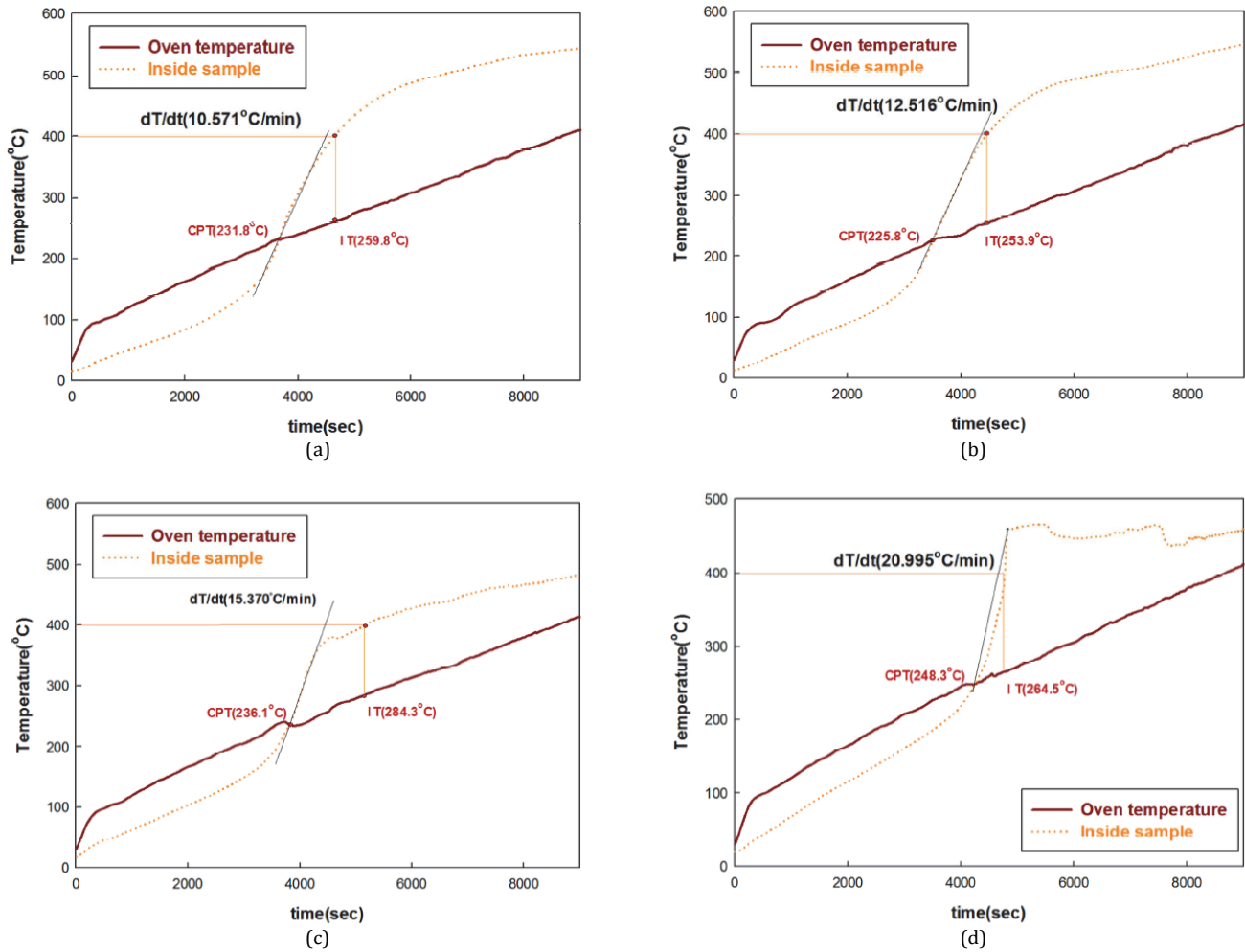


Fig. 6. CPT, IT, and CPS results of various samples. (a) Petcoke 0.6. (b) Bituminous C & A. (c) sub-bituminous KIDECO. (d) Wood pellet.

temperature of 264.5°C, which is high. However, it is confirmed that the time from ignition start temperature, to the onset of ignition temperature is short. The ignition initiation temperature of each fuel was not proportional to volatile secretion or fixed carbon consumption. In the case of C&A bituminous coal with stable flammability, it is confirmed that the ignition start temperature and ignition temperature are low. The ignition temperature at which the ignition starts, the flame is visible at 253.9°C, was very high. It is not likely that a fire will occur in a pulverizer using primary air at 250°C, as shown from the data on the temperature rise characteristics of each fuel. However, in order to predict the possibility of fire in the pulverizer of the power generation fuel, it is necessary to examine the heat generation rate (CPS; Cross Point-Slope; C/min) which predicts the time required for the flame to start from the heat generation start temperature.

In the case of petroleum coke fuel, the rate of temperature rise (dT/dt) from the onset of heat to the flame ignition temperature is shown in Fig. 6: it was 10.571 °C/min; KIDECO sub-bituminous coal's rate was 15.370 °C/min; and wood pellet's rate was very high, at 20.995 °C/min. Having the

low temperature-rising rate at 12.516 °C/min or less--for the petroleum coke, Kyung-dong anthracite and C&A bituminous coal--indicates to lower the chance of the onset of fire in a pulverizer, even when pulverized at 250°C or above. However, for wood pellets, the higher temperature-rising rate, at 20.995 °C/min, indicates the onset of fire in a pulverizer should be expected.

D. Temperature Rise Characteristics of Coal Pile

Coal-fired power plants store coal in a coal depot, open to the atmosphere. The site was open to ambient temperature and humidity, where 300 kg of coal piles were shaved for 20 days from September 1 to 20, 2016, and temperature changes were observed at depths of 5 cm (T1), 50 cm (T2) and 100 cm (T3). The measured results are shown in Fig. 7. The temperature variation of the C&A bituminous coal, which was classified as ignition-stable carbon on the spontaneous ignition index and ignition temperature-rise rate, was measured at the deepest point of the pile, at 100 cm (T3) and at 50 cm (T2). At T3, the temperature change was minimal,

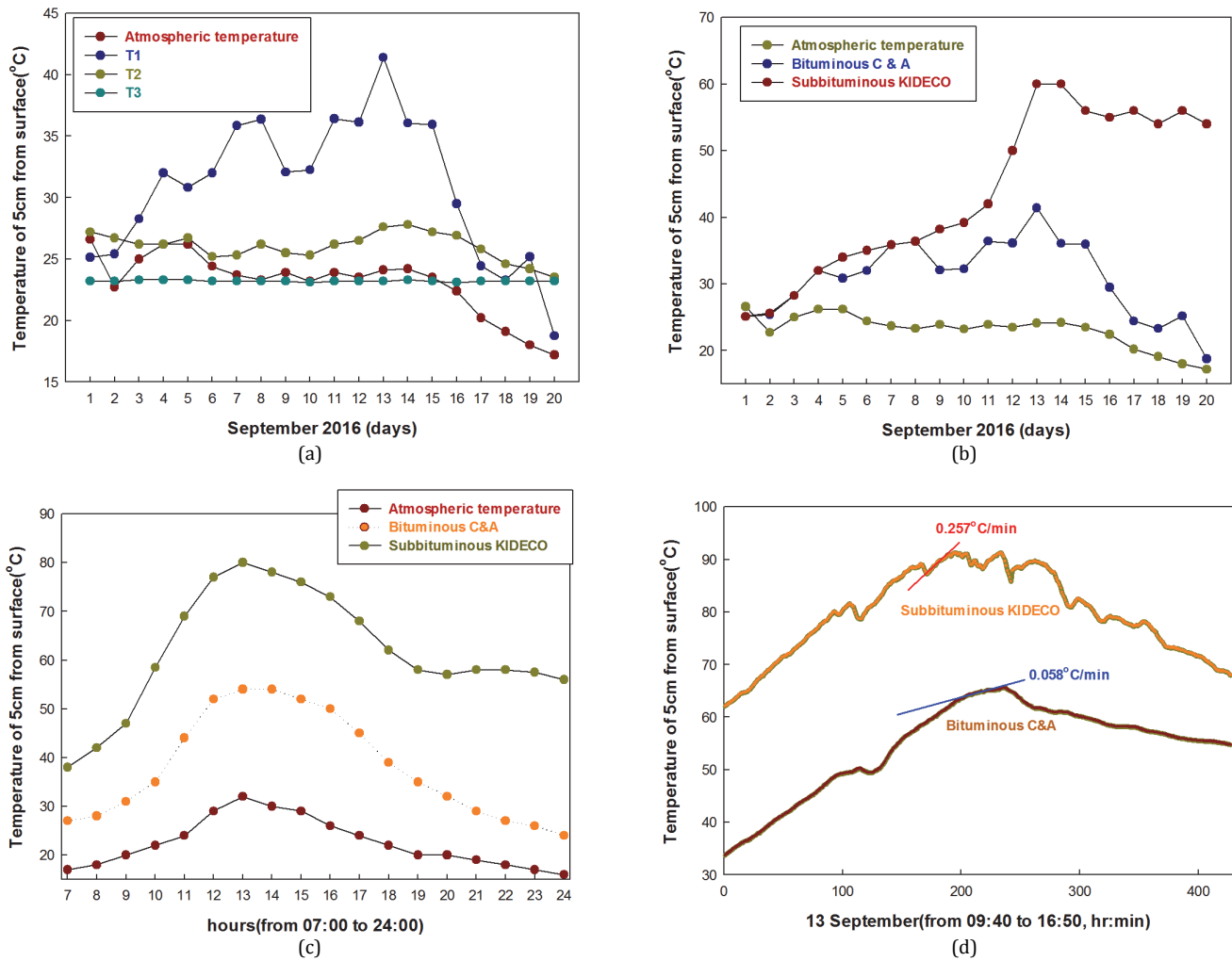


Fig. 7. Temperature profile of different coal types and thermocouple positions at coal stockpile. (a) Position of thermocouples (C & A). (b) coal type (T1 position). (c) coal type (hour interval). (d) coal type (minute interval).

and the recorded temperature was lower than the atmospheric temperature. However, at T2, while the temperature variance was minimal, the temperature was higher than that of the atmosphere. Depending on the type of coal, the temperature change at the depth of 5 cm (T1) was greater. At T1, the temperature of the coal pile for each coal type fluctuated to a large degree depending on the amount of radiation and conduction and convection conditions, while KIDECO sub-bituminous coal showed a characteristic of not being cooled by heat accumulation but having heat above a certain temperature. September 9th recorded the highest daily temperature average, and the average temperature for each hour was high when the radiation heat transfer was the highest, from 12:00p.m. to 2:00p.m., as shown in Fig. 7(c). C & A bituminous coal accumulates temperature proportional to the atmospheric temperature and then re-cools when the atmospheric temperature decreases. However, KIDECO sub-bituminous coal shows the highest temperature at noon and 1:00p.m., and maintained the temperature even when the

atmosphere temperature is decreased. In particular, the average temperature change per minute from 9:40a.m. to 4:50p.m., as shown in Fig 7(d), exhibited a trend of continuous increase until 14:10p.m. (270 minutes), and it was cooled afterwards. As for the temperature rise rate towards the maximum temperature, it was very high at 0.257 °C/min, making it more prone to ignition when exposed to higher ambient temperature. By contrast, the C&A bituminous coal registered a lower rate of 0.058 °C/min, making it relatively safer with regards to sudden ignition.

E. Physicochemical Correlation

To investigate the physicochemical correlation between spontaneous ignition stabilization and presence of antimicrobial, the distribution of surface hydrocarbons and oxygen bonds, combustion temperature and heat flux, specific surface area and pore characteristics of each fuel were investigated. The results of the XPS analysis of petroleum coke (Pet-coke 0.6) that has little possibility of ignition and

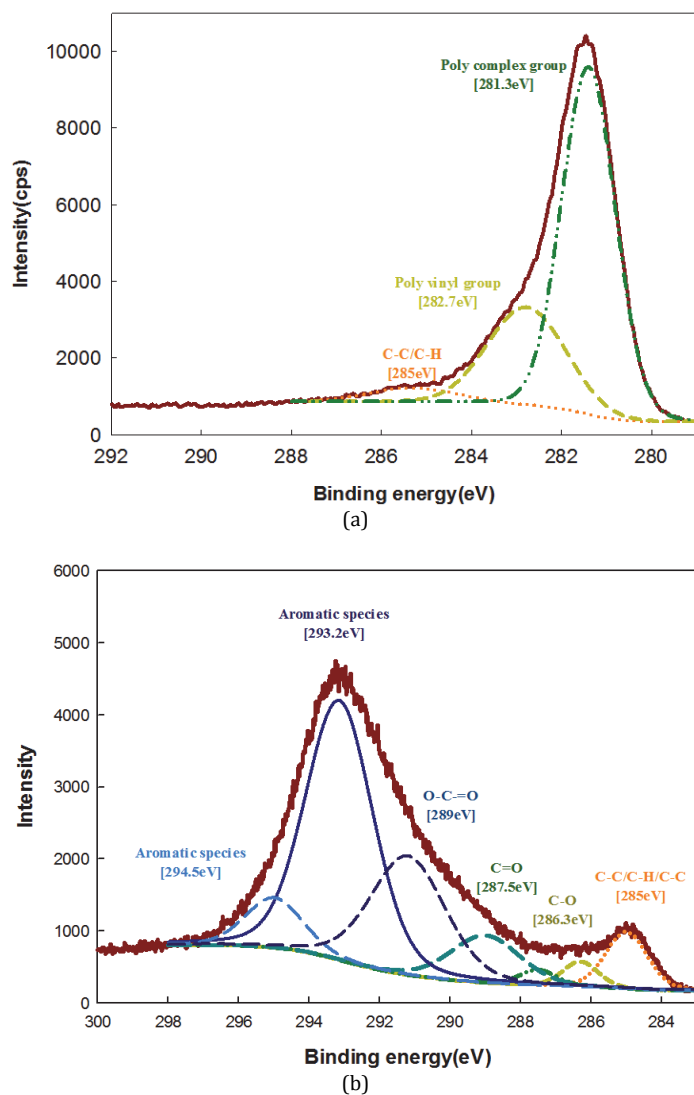


Fig. 8. XPS analysis of (1) Pet-coke 0.6 and (2) KIDECO samples surface.

KIDECO sub-bituminous coal with high possibility of ignition are shown in Fig. 8. Sixty percent of the petroleum coke (Pet-coke 0.6), the fuel with the highest carbonization rate, is composed of poly complex group materials, $(-C_6H_2(CH_3)_2O-)_n$, $(-CH_2C(CH_3)(CONH_2)-)_n$, $(-C(O)-CH_2-N(CH_3)-)_n$, Poly(2,6-dimethyl-1,4-phenylene oxide), Poly(methacrylamide), Poly(sarcosine) with the coupling energy at 281.3 eV. The rest is composed of poly vinyl group with coupling energy of 282.7 eV, and hydrocarbon (C-C/C-H) with coupling energy of 285 eV was present on the surface. On the other hand, the KIDECO sub-bituminous coal is composed mostly of aromatic species that have coupling energies of 293.2 eV and 294.5 eV, which are highly volatile even at a lower temperature range. In addition, the oxygen functional group (O-C=O, C=O, C-O) which enhances the spontaneous ignition is present at a high concentration. Higher concentration of surface oxygen functional group that accelerates the surface oxidation of the coal accelerates spontaneous ignition, while higher

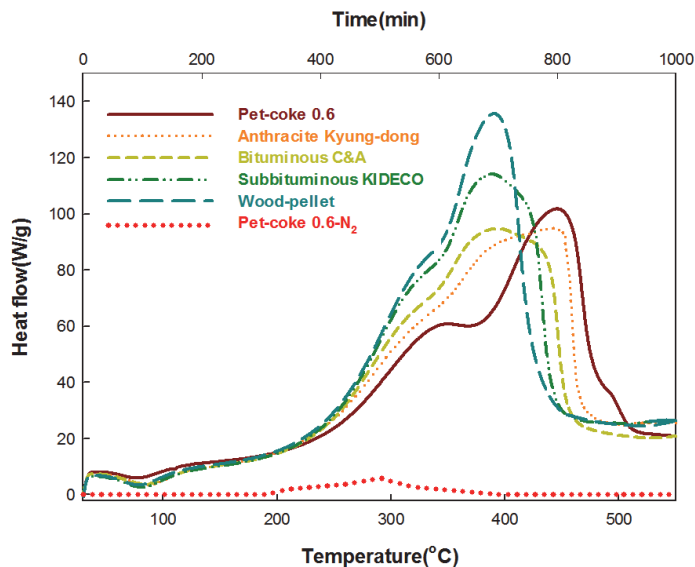


Fig. 9. Heat flux of various samples of heating temperature and time.

concentration of aromatic species, which devolatilized at lower temperature range, shortens the time between the ignition start to the flame generation.

In the case of low-grade sub-bituminous, which has a high ignition rate and low carbonization, the concentration of oxygen functional groups known as carboxyl, hydroxyl, carbonyl, and ether groups is high. The heat flux using DSC according to the heating temperature and time in the nitrogen atmosphere or the oxygen atmosphere for each power generation fuel is shown in Fig. 9, which is divided into several exothermic reaction regions. Generally, exothermic reaction peaks are divided into 2 to 3 regions according to the type of carbonaceous material, and oxidation reaction proceeds. The endothermic reaction, which is thought to be the loss of latent heat of evaporation at the initial 100°C, can be seen. The exothermic reaction proceeds during the devolatilization and the heat flow is constant. However, as a result of measuring the tendency of the heat flow to proceed while raising the temperature of the petroleum coke in the reducing atmosphere of the N₂ gas. The heat flow was hardly detected in the nitrogen atmosphere, but the oxidation reaction of the oxygen functional group the heat flow is assumed to be.

On the other hand, it can be seen that the heat flow temperature becomes higher with the degree of carbonization in the fuel. It can be seen that the lower the degree of carbonization, the higher the heat flux in the low-temperature region due to the higher content of oxygen functional groups and aromatics, which are composed of oxygen (O) and hydrogen (H) components, which are highly pyrophoric.

As shown in Table 5, the thermal diffusivity and thermal conductivity at room temperature did not show a significant correlation with the degree of carbonization, but the specific heat of molten steel was lower as the degree of carbonization increased. In particular, the specific heat of wood pellet is

Table 6
Surface area and pore properties of sample chars

Samples	BET surface area [m ² /g]	Pore volume [cm ³ /g]	Average pore diameter [nm]
Pet-coke 0.6	142	0.09	1.12
Kyung-dong	260	0.10	2.23
C & A	360	0.32	3.86
KIDECO	395	0.42	4.12

2.255 J/g·K⁻¹, which is twice as high as 1.188 J/g·K⁻¹ of C&A bituminous coal, which is a standard design coal. Also, petroleum coke and tungsten anthracite showed a lower range than standard bituminous coal. It is confirmed that the higher the specific heat is, the higher the ignition rising rate (CPS) at the heat generation starting temperature.

On the other hand, in the case of particle activated carbon, it is reported that when the ambient oxygen concentration is increased, the critical spontaneous ignition temperature (CSIT) is lowered [10], and the surface area and concentration of contact between the power generation fuel and oxygen in the air should be examined. In order to shorten the reaction time to the ignition temperature range where the flame is generated after the ignition start temperature at which the natural exothermic reaction starts, it is important to develop the specific surface area and pores of the coal after devolatilization of the power generation fuel. Table 6 shows the results of the BET analysis of the fuels produced after devolatilization in the nitrogen atmosphere of each power generation fuel. As shown in Table 6, the BET surface area, pore volume, and average pore diameter increase significantly as the power generation fuels with higher volatile content are carbonized. The specific surface area of petroleum coke (Pet-coke 0.6) char is 142 m²/g, while that of KIDECO sub-bituminous coal char is 2.78 times higher than 395 m²/g, indicating that KIDECO coal is not only spontaneous but also highly reactive. As the specific surface area of char is higher, the surface area of contact with oxygen, which accelerates the surface oxidation rate, becomes larger, so that contact with oxygen becomes smooth and the ignition increase rate (CPS) from the initiation of heat generation to the ignition increases.

V. CONCLUSION

The results of the study are as follows: 1) The ignition of coal depot and the occurrence of fire in pulverizer were investigated according to the pyrophoricity and physico-chemical characteristics of coal fired power plants.

First, in the case of petroleum coke fuel, the ignition rate from the start of ignition to the ignition temperature of flame is lowest at 10.571 °C/min. Wood pellets are high at 20.995 °C/min and are expected to be more likely to cause pulverizer fires.

Second, in the case of coal-type pile temperature at the surface part of the coal pile (depth: 5 cm), C & A bituminous coal accumulates temperature proportional to atmospheric temperature and re-cools when the atmospheric temperature decreases. On the other hand, KIDECO sub-bituminous coal accumulates atmospheric heat through radiation, conduction, and convection and shows a heat accumulation characteristic that maintains a constant temperature without being completely cooled even when the ambient temperature is low.

Third, KIDECO sub-bituminous coal, which has low carbonization, has a high concentration of aromatic species with high volatility and binding energies of 293.2 eV and 294.5 eV at low temperatures; also, oxygen functional groups (C=O, C-O and O-C=O) are very high. The specific heat of molar heat was lowered, as the degree of carbonization was higher. The specific heat of molar heat of the wood pellets with the lowest degree of carbonization was 2.255 J/g·K⁻¹, which was higher than 1.188 J/g·K⁻¹ of C and A bituminous coal. It is predicted that flame will occur soon after spontaneous ignition is started because it is about twice as high.

Fourth, the specific surface area of petroleum coke char with the highest carbonization is 142 m²/g, while the specific surface area of KIDECO sub-bituminous coal char with low carbonization is 395 m²/g, which is 2.78 times higher. It is confirmed that the BET surface area, porosity volume, and average pore diameter of char generated after the devolatilization reaction are increased by the initiation.

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