STUDY ON CRITICAL SELF-IGNITION TEMPERATURE OF LOW RANK COAL TO PREVENT SPONTANEOUS COMBUSTION IN A COAL MINE GOAF

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Low rank coals, such as lignite and sub-bituminous coal, are estimated to be 50 to 60% of total coal reserves in the world, but they have not been fully developed due to its uncontrollable self-heating characteristics except shallow open-pit mines. Spontaneous combustion of the low rank coals is an important key issue to promote their new utilizations for coal gasification power plants. It has been well-known that the spontaneous combustion of coal has been observed after the internal pile temperature is over the critical self-ignition temperature (CSIT). Although CSIT strongly depends on the coal-pile volume, previous laboratory measurements on self-heating rate of coal have been done using quite small amount of coal samples with focusing their chemical characteristics. It has been required to carry upscale experiments using changing coal volume up to 1 m$^3$ order, because the coal volume is also a dominant factor in the equation to expect CSIT.

In the present study, the characteristics of spontaneous combustion of the Chinese and Indonesian low rank coals have been investigated by both laboratory experiment and upscale experiment using the wire-mesh basket test with cubic baskets 2.5 to 10 cm and 25 to 100 cm in length, respectively. The experiments with the coal volume from 10$^{-5}$ to 1 m$^3$ have been carried out in order to measure (a) coal temperature-time curves in the coal-pile in different length of the baskets and ambient air temperature, (b) CSIT based on measurement results of different ambient temperatures, (c) a relation between CSIT and coal-pile volume, (d) thermal parameters for numerical simulations on spontaneous combustion of residual coal in a mine goaf.

The dissertation is composed of six chapters as follows:

Chapter 1 describes the role of coal, especially low rank coal against the world energy demand. The problems of spontaneous combustion at coal mines in China have been reviewed from standing points of mine safety and economic loss, because China has the largest coal production and consumption in the world. Furthermore, this chapter reviews experimental methodologies and theoretical approaches presented by previous researches to study coal spontaneous combustion or self-heating. The major physical parameters related to CSIT were defined based on the Frank-Kamenetskii (F-K) equation that was formulated from Arrhenius equation on oxidation and heat conduction equation to express heat balance in the pile.
Chapter 2 describes the experimental apparatuses and methodologies by the wire-mesh basket test. The laboratory and upscale experiments were done to cover coal volume of wire mesh baskets in range from $10^{-5}$ to 1 m$^3$. The laboratory and upscale experiments used crushed coal 0.43 mm or 42 mm in average length, respectively. The baskets were installed in the chambers controlling ambient air temperature constant from 40 to 150 ºC using electric controller and heaters. In the experiments, coal temperatures in the pile and CO$_2$ and CO gases emitted from coals were monitored continuously for 8 hour to 22 days depends on the basket length. Four low rank coals, consists three lignite called LE-1, LE-2, NE and one sub-bituminous coal (UE), were used for the laboratory and upscale experiments using the wire-mesh basket test after pulverizing coal samples into average lengths of 0.48 and 42 mm, respectively.

Chapter 3 describes the results of laboratory experiments using three cubic wire-mesh baskets for different ambient temperatures (40 to 150 ºC) to find CSIT for each coal sample. Based on the center temperature-time curves of three cubic baskets 2.5, 5.0 and 10 cm in length, values of CSIT for LE-1 were obtained as 143, 124 and 117 ºC, respectively. From a comparison of relations between CSIT and pile length for LE-1 and UE, coal sample LE-1 showed lower CSIT than UE. Thus, the equation of CSIT vs. pile length depends on coal properties such as activation energy and moisture content.

Chapter 4 discusses the results of upscale experiments with UE sample on CSIT for cubic baskets 25, 50 and 100 cm in length. The results using the 100cm basket showed quite different temperature-time curves on the heating process. Besides, the reductions of coal-pile height or volume in the basket were also measured to analyze characteristic diversification of the coal samples. The most important result was the value of CSIT evaluated by the wire-mesh basket 1m$^3$ in volume. It has been evaluated to be a reliable result to extrapolate CSIT value for industrial coal stockpiles with volume of 100 m$^3$ order.

Chapter 5 explains the numerical simulation results on spontaneous combustion at a goaf area after longwall mining in the underground coal mine. The measured values of CSIT and activation energy were applied to the numerical simulations to find a mine operation to avoid spontaneous combustion of residual coals at the goaf. The numerical simulation results showed that the goaf area can be classified into three zones. It was also confirmed that the method injecting grouting slurry is effective to increase activation energy of residual coals and decrease porosity of goaf area consists residual coals and fall rocks. It was expected that the grouting slurry prevents the coal spontaneous combustion in the goaf. Oxygen concentration measured by the tube-bundle system was compared with the numerical simulation results and also proved that the slurry grouting method is effective and economical to prevent spontaneous combustion.

Chapter 6 presents the conclusions of this study on spontaneous combustion of the low rank coal. It contains a summary of the findings on the equation to predict CSIT values vs. pile length or volume based on measurement results by the laboratory and upscale wire-mesh basket tests and applying the CSIT to the numerical simulations on spontaneous combustion of residual coal in the goaf area.