Ignition Behavior of Single Coal Particles From Different Coal Ranks at High Heating Rate Condition

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ABSTRACT

The ignition behavior of single coal particles of five kindes of coal with different ranks (low volatile bituminous, low volatile sub-bituminous, high volatile bituminous, lignite) with particle size of 150-200μm was investigated at high heating rate condition. Particles were injected into a laminar flow reactor and the ignition behavior was observed with high speed cinematography. Sub-bituminous were observed to ignite homogeneously; however, low volatile bituminous coal and lignite undergo fragmentation prior to igntion. The observation was analyzed with previous work.

Key Words : Ignition, LFR, Fragmentation, coal rank, particle size

Ignition of pulverized coal particle is a fast but complicate process. At high heating rate, during a time in the order of 10^1 ms or even less, both gas phase combustion of released volatile matter and heterogeneous combustion of particle surface take place. Many previous studies were done to investigate the ignition process. The initial ignition of PC particle could be homogeneous ignition of released volatile matter or heterogeneous ignition on char surface depending on the coal rank, particle size, coal feeding rate, heating rate and the ambient gas condition such as gas composition, oxygen concentration and temperature. Many previous works were done to investigate the factors mentioned, and several typical methods of studying ignition were developed, such as by investigating weight loss, temperature changes, and direct optical observation. This manuscript studied ignition mechanisms of single PC particles as a function of coal rank and particle size by direct optical observation.

Five different coals with different ranks are investigated in this research. The properties of the fuels are shown in table-1.

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Table 1 Proximate analysis of coals

	Proximate analysis (as received) [%]			
	Moisture	VM	FC	Ash
Coal FX	1.2	12.4	78.6	7.8
coal A	1	23	66.9	9.1
coal D	2.5	34.7	54.4	8.4
coal Adaro	5.2	50.7	39.9	4.2
Coal Kideco	32.2	40.8	24.7	2.3

Experiments were carried out in an entrained-type laminar flow reactor at Pusan Clean Coal Center. A schematic of the system was shown in figure 1.

The reactor was designed with a honeycomb structure and a circular cross section to make sure the symmetry of the temperature and gas composition condition along the horizontal plane. A quartz tube with rectangular cross section was set above the reactor to isolate the inner reacting zone and to decrease the heat loss. A non-premixed flat flame was made using CO & H_2 as fuel and O_2 as oxidizer to provide a high-temperature condition above the reactor. N2 with also used to control the temperature, oxygen concentration and the velocity of the post-flame gases flow. The PC particle inlet was designed at the center of the reactor using N2 as carrier gas. The calculated composition of the post flame gas was shown in table 2.

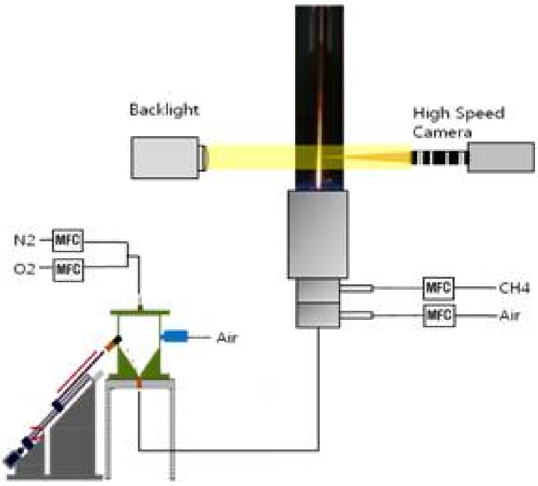


Fig. 1 Schematic of Laminar flow reactor and cinematography system

Table 2 Calculated composition of post-flame (mol%)

CO2	H2O	O2	N2
20.9%	8.4%	21.6%	49.1%

The gas temperature profile along the reactor centerline was measured with a 125-μm type R thermocouple and corrected for radiation losses. The corrected gas temperature as a function of the height above the reactor is shown in fig. 2.

PC particles were fed into the reactor with a feeding rate less than 0.001g/min to make sure a single-particle feeding condition and to guarantee that the condition of the reacting zone would not be affected by the combustion of the PC particles. The ignition behavior of PC particle was captured by a Photron FASTCAM SA4 high speed camera. Since ignition process takes place in the order of 101 ms including both gas phase reaction and heterogeneous reaction at high heating rate condition, a frame rate of 10000frame/sec was selected. To capture PC particles before ignite when no light was released, a backlight using Photron HVC-UL was used oriented to the high speed camera.

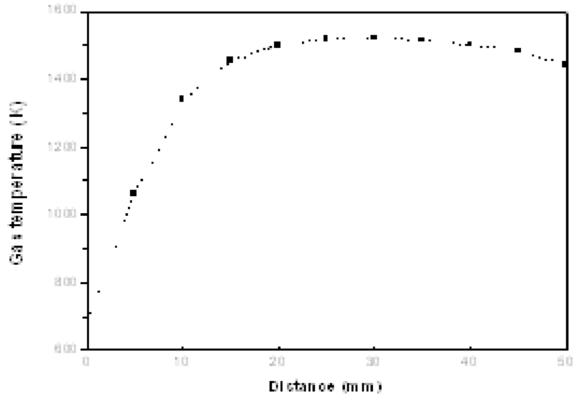


Fig. 2. Temperature distribution in the vertical direction above the burner along the centerline

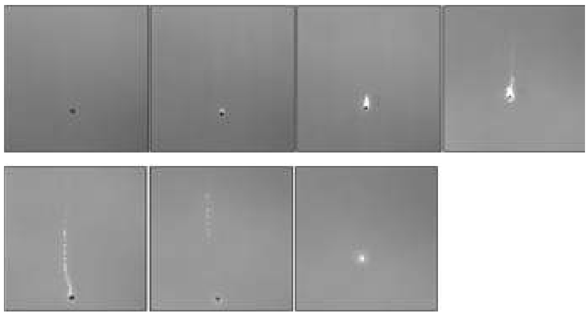
The behavior of coal particles with size of 150-200μm was shown in fig. 3. Coal A and D had similar ignition phenomenon. After being injected into burner, as coal particle heated up, homogenous ignition takes place after the gas phase volatile was released from the particle. It appears that the gas phase volatile undergoes a certain distance prior to ignition (Fig. 4), and then a diffusion flame was formed along the gas flow streamline above the particle. As more gas phase volatile was released the gas phase volatile combustion flame became bigger to surround the particle. This results is consistent with the schematic representation of the formation of soot tails proposed by T. H. Fletcher [14]. Prior to the extinction of gas phase volatile combustion, a condensed tail with direction oriented along the gas flow streamline was formed above the particle, which is believed to be tar combustion [4. 14, 15]. The tar combustion last a longer time than gas phase volatile combustion and has a length times of the PC particle itself. It appeared that solid coal particle remained dark black prior to extinction of gas phase volatile combustion and become bright at the end of gas phase volatile combustion, which means heterogeneous ignition initiated. Tar combustion continued after heterogeneous ignition happened and burnt out prior to char burn-out.

Coal Adaro ignited homogeneously as well as coal A and D. However, long tar combustion tail is not found during volatile combustion. Previous work [1] showed that most sub-bituminous coals have relatively low content of tar during devolatilization process. Coal adaro also showed the same tendency comparing with coal A and D.

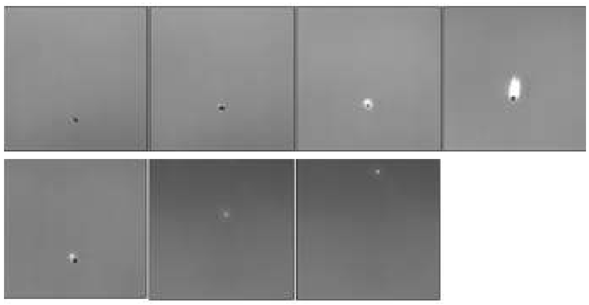
Using lens with high magnification, it's observed that prior to gas phase volatile extinction, solid particle ignited heterogeneously at points that have sharply changed surfaces [Fig. 5]. Y. A. Levendis et al. [2] employed 'hot spot' to explain the initial ignition points on char surface. They suggested that the hot spots on char particle surface could result from several causes, such as local mineral concentrations that catalyses and accelerate reaction or localized macro- and transitional pores that serve as feeders to the micro-pores and enhance reactivity. In Y. A. Levendis et al. later work [3], they observed all of the particles ignited heterogeneously at hot spots at their surfaces and they pointed out that hot spots may be constituted by sharp edges or other deformations, mineral inclusions, etc. However, at the condition in this research, it appeared that the hot spots always localize in the point that would easily diffuse to and that has higher surface area to mass ratio, such as a protruding angle. In C. R. Shaddix and A. Molina's work [1], they showed that during devolatilization of the Pittsburgh coal (bituminous) soot cloud temperature is hotter than the ambient due to diffusion flame and the coal particle temperature of Black thunder coal (sub-bituminous) was lower than the ambient, possibly because the oxygen was prevented from reaching the particle surface by volatile diffusion flame. They proposed that the temperature of the soot cloud of Pittsburgh coal would be hotter than the ambient by 300-400K due to volatile combustion at the similar oxygen concentration of with this work, so oxygen concentration would be dominated factor that affects the reaction of char. At the sharp edges of the particle, oxygen concentration would reach the critical value that is necessary for ignition happens in a shorter time due to a short distance for diffusion.

Coal FX showed a very different phenomenon with both coal A and D. Most of the particles encountered fragmentation prior to ignition. Coal particles fragmented into small pieces without significant volatile release. Fragmentation lasted about 20ms. At the beginning of fragmentation, small pieces of fragments separate from the main particle with very high velocity (about 4m/s) and the main particle was rotated and accelerated by the momentum changes due to the separation of small pieces. Then main particle fragments into several primary fragments with volatile release and ignition. The primary fragments then fragments into smaller fragments with different sizes(10μm-80μm) and ignite (Fig. 6). It observed that relatively large fragments undergo homogeneous ignition and heterogeneous ignition in sequence. However, some of the particle didn't fragment. Similar with the case of coal A and coal D, homogeneous ignition takes place first and then heterogeneous ignition takes place. But the diffusion flame is much small comparing with coal A and D due to its less volatile matter content, and no long tail was formed above the particle.

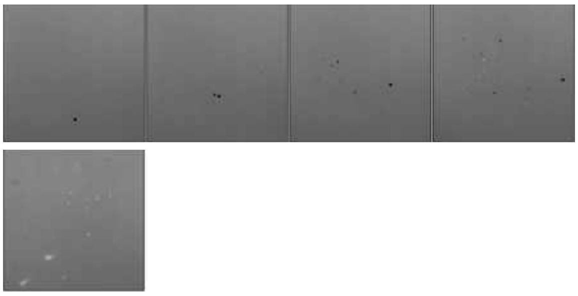
Most of coal Kideco particles also undergoes fragmentation prior to ignition. However, the fragmentation last about 10ms, which is shorter than that of coal FX. Some of the particles who don't fragment undergo similar phenomenon with the case of coal A and coal D.



(a)



(b)



(c)

(d)

Fig. 3. Ignition behavior of coal particles with size of 150-200, (a) coal A, (b) coal Adaro, (c) coal FX, (d) coal Kideco

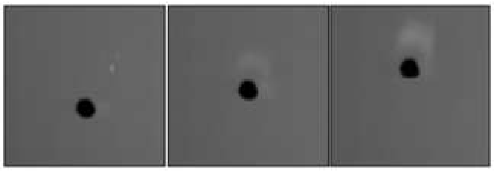


Fig. 4. Ignition of volatile matter, coal A, 150-200μm

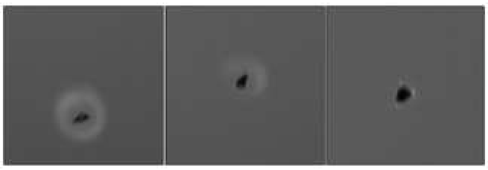


Fig. 5. Ignition of char particle, coal A, 150-200μm

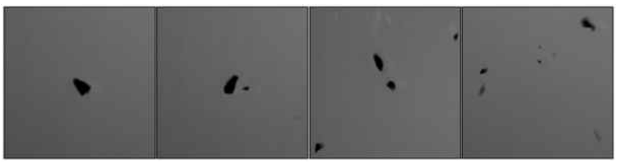


Fig. 6. Fragmentation of coal FX particle with size of 150-200 (a) coal particle before fragmentation, (b) primary fragmentation, (c) fragmentation with ignition of released volatile, (d) fragmentation into smaller pieces.

Acknowledgments

This work was supported by the second phase of the Brain Korea 21 Program in 2011.

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