Title: Spherical flame propagation behavior of pulverized coal particles and ammonia in a turbulent environment.

By; HADI bin Khalid

Summary of the present study

The aim of the present study is to clarify the flame propagation behavior of pulverized coal particle clouds for mixing combustion of low ignitability coal and ammonia. Expected that ammonia as an energy carrier would improve the ignition characteristics of coal particles in the coal-ammonia mixing combustion. To make a comparison, common bituminous coal also used as the fuel in the present study. The intention of the study is the combustion in a turbulent environment. The three categories of the experiment were performed; pulverized coal combustion, ammonia combustion, and pulverized coal-ammonia (mixing) combustion.

The unique experimental apparatus was developed to suit all categories of combustion in a turbulent environment. The experiments on spherical flames propagations were performed by using a spherical-inner shape closed vessel. The turbulent flow field in the vessel generated by counter-rotation of two identical fans. The turbulence intensity was changed by changing the fan rotational speed. A linear relationship between fan rotational speed, N and turbulence intensity, u' was obtained from particle image velocimetry (PIV) measurements. The turbulence was considered homogeneous, and there was no regular bulk motion in the center of the combustion vessel. The fans were turned OFF for the experiments in a quiescent environment. A dispersion system was designed to disperse the pulverized coal particles into combustion field. The pulverized coal was dispersed homogeneously in the combustion field by 300 kPa dispersion gas (ambient gas). It was confirmed that the dispersion flow was not influencing the flame propagation behavior.

Using the present experimental apparatus, the pulverized coal clouds showed no flame propagation by using the air as the ambient gas. Therefore, diluted oxygen (40 vol%

O_2 and 60 vol% N_2) was used as the ambient gas to achieve flame propagation. To make a qualitative comparison, the ammonia and mixing combustion also used the similar ambient gas. However, to validate the present experimental methods, experiment on the ammonia-air mixtures was performed to compare the present results to the previous research results that available in the literature.

Common bituminous coal (C5) with fuel ratio = 1.56, and three types of low ignitable coal consist of TW, KK and UL with fuel ratio of 2.5, 3.17 and 5.3, respectively were tested in the present study. Fuel ratio is the ratio of fixed carbon to the volatile matter. Low ignitable coals have higher fuel ratio than common bituminous coal. In general, more higher fuel ratio is difficult to ignite. In the coal combustion of C5 coal for various coal concentrations and turbulence intensities, the turbulence intensity has a significant effect on flame propagation velocity, compared to the effect of coal concentration. This is due to the effect of turbulence heat transfer. Turbulence heat transfer increased the volatile release rate, thus increased the flame propagation velocity. Flame propagation capability of low ignitable coals for various coal concentrations and various turbulence intensities also clarified. Moreover, the effects of gravity, turbulence intensity, and fuel ratio on the spherical turbulent flame propagation behavior of C5, TW and KK coal particle in a turbulent flow field were clarified by experiment under 1g and μg environments. In μg, the coal particle cloud is more flammable than in the 1g environment. Natural convection, which exists in the 1g environment, has a significant effect on the flame propagation behavior of C5 and TW coal particle cloud in a quiescent environment.

Ammonia-air and ammonia-O_2N_2 premixed combustion experiments were performed for various equivalence ratios and turbulence intensities. Flame propagation behavior of ammonia-air in the quiescent environment was obtained and showed good agreement to the previous study in the literature. Flame propagation probability limit for the ammonia-air mixture in various turbulence intensities was clarified. The ammonia-air mixture in lean condition tended to sustain flame propagation even in higher turbulence intensity, up to 1.29 m/s. In quiescent environment, the limit of equivalence ratio of ammonia-air to sustain the flame propagation is between 0.7 to 1.2, which is similar to the previous study, while for ammonia-O_2N_2 is between 0.4 to 2.0. Flame propagation velocity for ammonia-O_2N_2 mixture was obtained and compared to the characteristics of ammonia-O_2N_2 flames in the mixing combustion.

Mixing combustion of coal-ammonia-O_2N_2 mixtures was experimentally studied for the C5, TW, KK and UL coal for various turbulence intensities. The coal concentration was set to 0.6 kg/m^3, and the equivalence ratio of ammonia-O_2N_2 is 0.6. Considering the coal concentration of 0.6 kg/m^3 is the practical used, and the ammonia-O_2N_2 mixture in lean condition was selected. Without ammonia addition, the KK and UL coal were not sustaining flame propagation, while TW coal was sustained flame propagation only in the high turbulence intensities. The ammonia as an energy carrier was increased the flame propagation velocity of C5 coal in mixing combustion about five times. In addition, ammonia flame increased the ignition capability of low ignitable coals. Ammonia flame increased the volatile release rate of the coal particles, thus flame propagation velocity increases. Therefore, TW, KK and UL coal sustained the flame propagation in all turbulence intensities tested in the present study. Turbulence intensity has a significant effect on flame propagation velocity of mixing combustion, similar to the coal combustion. Based on the lower heating value (LHV), with ammonia addition (equivalence ratio = 0.6) and coal concentration of 0.6 kg/m^3, coal particles can be saved around 20% (weight %). The findings of the present study can contribute to the fuel cost reduction and the improvement of energy security by being able to utilize low ignitable pulverized coal particles. Moreover, in the coal-fired boiler, expected that the co-firing of coal-ammonia help to increase the burner stability, concerning the flame propagation velocity is one of the important parameters for flame stability.