Auto-ignition of Metal Particles in Oxygen Atmosphere

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1 Introduction

Last decades much attention has been paid into combustion in multiphase media where a liquid or solid fuel burns in a gaseous oxidant. Particular interest is connected with the ignition and combustion of metal particles. Today metal powders are widely used as fuel additives in various energetic materials such as propellants, explosives, and pyrotechnics due to its high volumetric and gravimetric combustion enthalpy. Nano-sized energetic particles offer the potential of controlled burning rates, increased combustion efficiencies, and reduced sensitivity. Aluminum nanoparticles have been widely investigated for their ability to energetically-enhance combustion [1, 2].

Recent numerous experimental studies were connected with the explosibility of metal dusts [3, 4]. First of all it was associated with increasing amount of accidents at industrial plants when spontaneous explosions and conflagrations have place due to unexpected ignition of metal dusts. This work has been conducted for determining conditions that can provoke spontaneous ignition of the metal dust in oxygen atmosphere. The Rapid compression machine (RCM) was implemented for generation of necessary thermodynamic conditions.

The ignition was investigated at pressures ranged from 1.5 MPa and temperatures ranged from 800 K. The different separated and not separated fractions of metal particles with size ≤ 200 μm were studied. The auto-ignition conditions for different particle sizes and stoichiometries of metal dust – oxygen medium were investigated. Also conditions which can force combustion evolution were established.

2 Experiments

Rapid Compression Machine (RCM) models a single compression event of an engine. Gases contained in the reaction chamber are compressed to high pressures and temperatures for few milliseconds and the reaction is allowed to proceed at a constant volume at the end of a compression stroke. Typically, post compression pressure greater than 5 MPa and temperature greater than 1000 K can be obtained. In order to avoid significant heat losses and reaction happening before the end of the compression stroke, the piston should be travelled very fast. To achieve these high velocities, the piston is usually driven pneumatically and stopped hydraulically. The compression ratio, initial pressure, temperature and composition of the mixture can be varied to control the pressure and temperature histories after compression.

The design of the developed for this study RCM is based on several other compression machines described elsewhere in the literature [5, 8]. The general view of the machine is shown in

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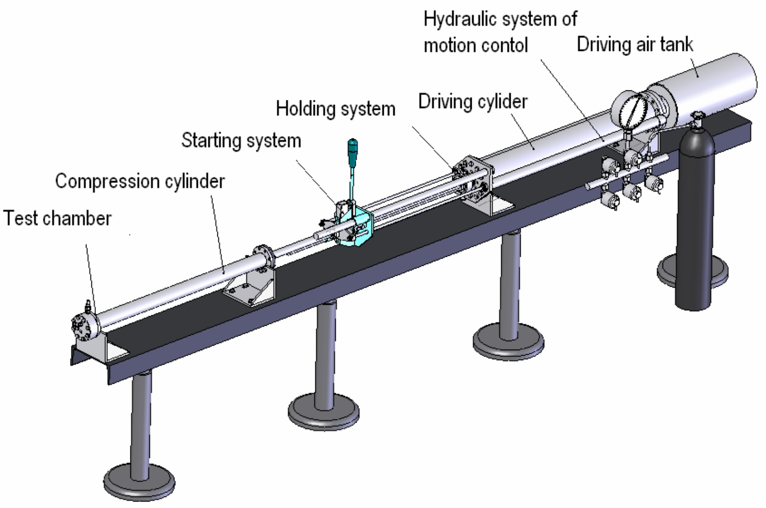

Figure 1. General view of the developed RCM

Fig.1. The RCM system consists of a driving cylinder, a compression cylinder, a hydraulic system of motion control, and a driving air tank. All these parts are located along one line.

For these experiments metal particles were placed into the combustion chamber. The chamber flange was equipped with a special valve and a pressure transducer. For optical excess, a quartz cylinder was mounted into the wall of cylindrical chamber. The doubled optical fibers transferred the recording luminescence at metal particles ignition and combustion to the photomultiplier tubes. In experiments the volume luminescence was only as the indicator of the presence of the reaction in the test chamber.

Experiments were performed at constant initial pressure of oxygen in the RCM channel equal to 25.0 kPa and at the initial temperature of 293 K. The height of combustion chamber was 30 mm. The piston stroke and the tank pressure of RCM were variable. For these experiments the mass of metal particle samples was varied. The particle size distribution of the used metal powder and the characteristics of the separated particle fractions are presented in Table 1.

Table 1. Characteristics of particle fractions used in combustion experiments

Fraction	1	2	3	4	5	6
Size, μm	160-200	100-160	80-100	63-80	50-63	≤ 50
Particle size distribution of mixture F, mass %	6.6	29.7	20	11.8	15.8	15.9

3 Results

In the first experimental series a not separated fraction of particles F was placed to the bottom of the combustion chamber (Fig. 2). For these conditions, the particle ignition was not observed for the pressures less than 1.9 MPa and temperatures 750 K. At conditions close to these limiting one’s, the ignition process was unstable. For these conditions the incomplete combustion of particles was strongly dependent on the heat flux from the forming reaction zone to the wall. The thicker particle layer resulted in the higher heat losses. From photos in Fig. 3 it is seen that the local ignition does not result in combustion of entire particle layer, the ignition arose only along the periphery of the samples where the thickness of the layer of particles was minimal.

Figure 2. Photographs of test chamber with particle sample before (left) and after compression (right)

Figure 3. Photographs of test chamber with particle sample after compression for near critical conditions

There are a number of factors that affect the behavior of “metal particles –oxygen” medium. These are a rate of oxygen compression, a rate of heat removal from the combustion region, and a particle size distribution. A combination of these and other factors determine a scenario of the process. In this case, a predominant size of metal particles in the vicinity of the primary auto-ignition zone plays an important role. To evaluate the influence of this factor, the ignition properties of individual particle fractions with the characteristic sizes cited in Table 1 have been studied. To facilitate the comparison different fractions were tested at the same time and at the same thermodynamic parameters of the gas. For that, particle fractions were located within separate cells of special racks made of stainless steel plates and inserted into the test volume (Fig. 4). For lower compression ratio experiments, all fractions of metal particles were not ignited. The higher compression ratio experiments demonstrated the auto-ignitions and combustion of fractions 3, 5, 6 and not separated mixture of particles. In addition, the localize auto-ignition and combustion of individual particles (1-2 pellets) were revealed in fractions 2 and 4. Only the biggest fraction 1 with particle size ranged from 160 to 200 μm was not ignited. The combustion completeness was largest in fractions 6, 3 and not separated mixture of particles.

Figure 4. Plan of the fraction location on the rack shelves (left) and photographs of test chamber before and after compression .

Conclusion

Auto-ignition and combustion studies of metal particles in oxygen atmosphere in rapid compression machine have been performed. Preliminary experiments in oxygen atmosphere shows that at thermodynamic conditions of $P \geq 1.2$ MPa; $T \geq 750$ K the bulk of metal particles with sizes less than 200 μm demonstrates strong abilities for both local auto-ignition and combustion. The unique correlation between the occurrence of ignition and stoichiometry of the “metal particles –oxygen” system wasn’t obtained.

References

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