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Effect of aluminum dust on flammability of gaseous epoxypropane in air

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HIGHLIGHTS

- Aluminum dust has significant effect on flammable limit of gaseous epoxypropane in air.
- LFL of gaseous epoxypropane in mixtures decrease as aluminum dust concentration increase.
- Combustion pressure of mixtures reached maximum at epoxypropane concentration of 7% or 15% (v/v).
- Combustion temperature of reached maximum at gaseous epoxypropane concentration of 7% (v/v).

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ABSTRACT

Through a series of experiments carried out in a 5 L confined vessel, the flammability of the gaseous epoxypropane/aluminum dust/air mixtures at various aluminum dust concentration has been analyzed, and the results are discussed. Variation of the aluminum dust concentration within the studied range was found to have significant effect on the LFLs (lower flammability limits) of gaseous epoxypropane in the hybrid mixtures. The LFL of gaseous epoxypropane is 2.1% (v/v) for the gaseous epoxypropane/air mixtures without aluminum dust. When the concentrations of aluminum dust are 70 g m^{-3}, 80 g m^{-3}, and 200 g m^{-3}, the corresponding LFLs of gaseous epoxypropane are 1.4%, 1.1% and 0% (v/v) respectively. The combustion pressure of the hybrid mixtures reaches maximum at the volume fraction of gaseous epoxypropane of 7% or 15% (v/v) which is higher than stoichiometric volume fraction of gaseous epoxypropane in the gaseous epoxypropane/air mixtures. The combustion temperature of the hybrid mixtures reaches maximum at the volume fraction of gaseous epoxypropane of 7% (v/v).

1. Introduction

Epoxypropane and aluminum powder are applied widely in industry fuel [1]. At atmospheric pressure and room temperature, epoxypropane is liquid. When it is used, liquid epoxypropane evaporates into the air and mixes with air to form flammable gaseous epoxypropane/air mixtures. Many studies on epoxypropane have been focused on its chemical reaction mechanism [2], the combustion and detonation products characteristics during its shock-to-detonation transition process [3–5].

Aluminum powder has higher energy and density [6], and is commonly used to mix with liquid fuel. The mixed fuel is generally used in a multiphase state. The combustion efficiency of mixed fuels depends on the proportions between components and requires the understanding for the flammability of gaseous epoxypropane/aluminum dust/air mixtures.

Dust/gas mixtures are frequently named "hybrid" mixtures [7–13]. Many studies were carried out on metal dusts [14–18] and aluminum dusts flammability data could be found in various articles, mostly focused on the determination of flammable sensitivity parameters (minimum ignition energy and temperature, and minimum flammable concentration) and combustion severity characteristics (maximum combustion pressure and maximum rate of pressure rise) [19–23]. The combustion pressure and temperature of gaseous epoxypropane/air mixtures has been studied also [1,5]. However, few studies include the effect of aluminum dust on flammability of gaseous epoxypropane in air and the combustion characteristic of gaseous epoxypropane/aluminum dust/air mixtures.

Through a series of experiments carried out in a 5 L confined vessel, the LFLs of gaseous epoxypropane in the hybrid mixture at various aluminum dust concentration have been obtained. The influence of aluminum dust concentration on the flammability of gaseous epoxypropane in air have been analyzed and discussed, and the combustion characteristics of the hybrid mixtures with different concentrations of gaseous epoxypropane and aluminum dust have been studied.

2. Experimental apparatus and procedures

The experimental set-up used in this study consisted of a 5 L cylindrical vessel coupled with an electric ignition system and a data acquisition system [24], as shown in Fig. 1. Experiments were

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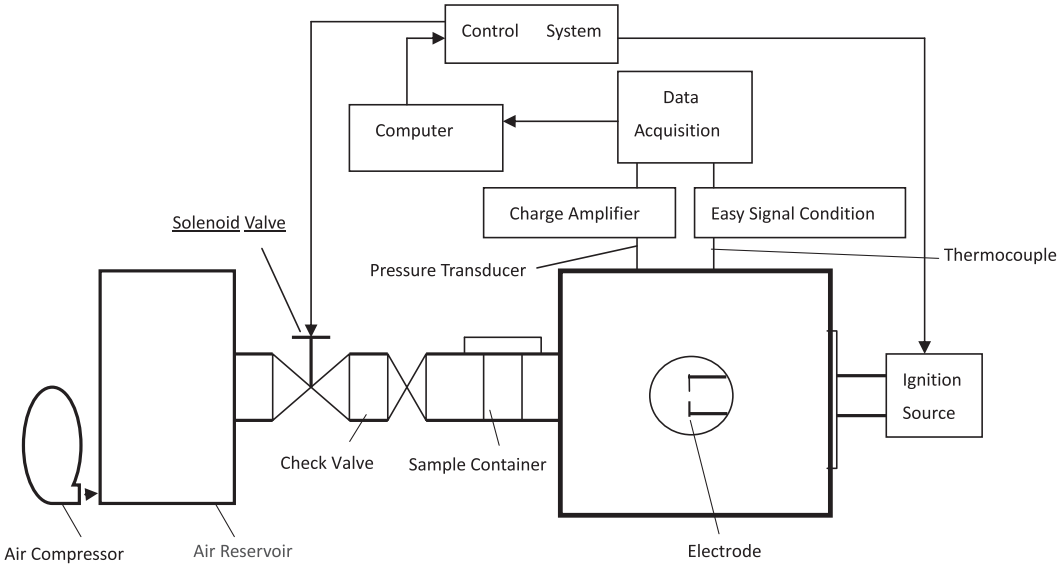

Fig. 1. Explosive experimental device of vapor/dust.

performed in the cylinder combustion vessel with central ignition. The height h of the vessel was 160 mm and the inner diameter $2R$ was 199 mm. In the experimental vessel, ignition was achieved by means of an inductive–capacitive spark produced between stainless steel electrodes with rounded tips, separated by a spark gap of 3 mm.

The ignition system consisted of an electric ignition rod and an electric spark generator. The electric energy produced by the spark generator was 22.68 J. The discharge capacitance and voltage for ignition were 14 μF and 1800 V respectively. The duration for dust injection was 10 ms. The room temperature was 25 °C and the environmental humidity was 33%. The mean size of the flake aluminum particle used for the study was about 5–20 μm.

3. Effect of aluminum dust on lower flammability limit of gaseous epoxypropane in hybrid mixtures

The addition of aluminum dust to a gaseous epoxypropane/air mixture has a significant impact on the lower flammability limit of gaseous epoxypropane the hybrid mixtures. For a given concentration of aluminum dust, the lowest volume fraction of gaseous epoxypropane at which combustion of the aluminum/gaseous epoxypropane/air mixtures can be initiated one time at least in seven repeated experiments is called the LFL of gaseous epoxypropane in the mixture.

The occurrence of combustion in the experimental vessel was determined through the evolution of the measured pressure. The LFLs of gaseous epoxypropane in the hybrid mixture at various aluminum dust concentration were determined through the experiments. Effect of aluminum dust concentration on the LFL of gaseous epoxypropane is shown in Fig. 2. It can be observed from Fig. 2 that concentration of aluminum dust has a significant effect on the LFL of gaseous epoxypropane in the hybrid mixtures. The LFL of gaseous epoxypropane is 2.1% (v/v) for gaseous epoxypropane/air mixtures without aluminum dust. When the concentrations of aluminum dust are 70 g m^{-3}, 80 g m^{-3}, and 200 g m^{-3}, the corresponding LFLs of gaseous epoxypropane are 1.4%, 1.1% and 0% (v/v) respectively. The LFLs of gaseous epoxypropane in the hybrid mixtures decrease rapidly as the concentrations of aluminum dust increase. The experimental results for the LFL of gaseous epoxypropane in the hybrid mixtures are listed in Table 1.

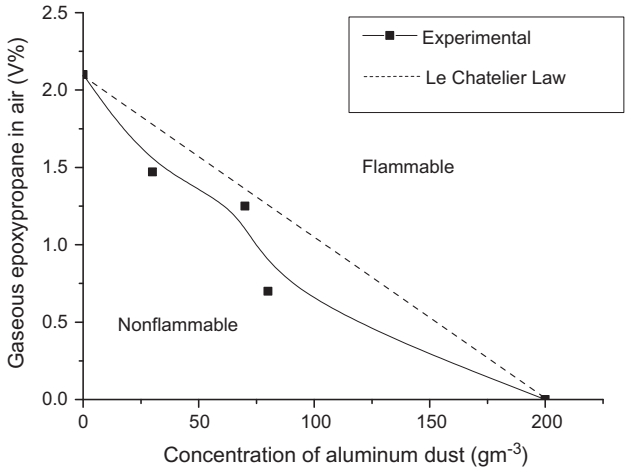

Fig. 2. LFL of gaseous epoxypropane in the hybrid mixtures vs concentration of aluminum dust.

Fig. 2 shows that gaseous epoxypropane/aluminum dust/air mixtures, for concentrations lower than the corresponding limit concentrations, either for gaseous epoxypropane/air or aluminum dust/air mixtures, can form flammable mixtures. The data represented in this figure show a significant disagreement from the linear relation indicated by the Le Chatelier's Law. Pilão et al. [12] and Dufaud et al. [25] presented details of the Le Chatelier's Law respectively.

4. Effect of aluminum dust concentration on combustion parameters

In the experiments, the combustion parameters of gaseous epoxypropane/aluminum dust/air mixtures were obtained at a given concentration of gaseous epoxypropane and various concentrations of aluminum dust. Combustion pressure time history and temperature time history of gaseous epoxypropane/aluminum dust/air mixtures at 1.4% (v/v) of gaseous epoxypropane and at various concentrations of aluminum dust are shown in Figs. 3 and 4 respectively. The maximum rate of combustion pressure rise $(dp/dt)_{max}$ and maximum combustion pressure p_{max} were then ob-