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Combustion parameters of gaseous epoxypropane/air in a confined vessel

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HIGHLIGHTS

- ▶ Combustion pressure and temperature of epoxypropane/air reach highest at concentration 7%.
- ▶ Ignition energy has significant impact on upper flammability limitation of epoxypropane/air.
- ▶ Combustion pressure of epoxypropane/air reaches highest near lower flammability limitation.
- ▶ Combustion temperature of epoxypropane/air reaches highest near lower flammability limitation.

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ABSTRACT

We present an ignition energy measurement system, which comprises a 5 L explosion vessel, a transient pressure measurement sub-system, and a transient temperature measurement sub-system. Through a series experiments carried out with this system, the influences of the concentration of gaseous epoxypropane on the combustion pressure and temperature and on the rate of combustion pressure rise and combustion temperature rise have been analyzed, and the results are discussed. The combustion pressure and temperature of gaseous epoxypropane/air mixtures reached their highest values at a concentration of 7% within the studied range. Variation of the ignition energy within the studied range was found to have little effect on the combustion pressure or temperature of the gaseous epoxypropane/air mixtures. However, it had a significant impact on the upper flammability limit. The variation trends in the combustion pressure and temperature and the rate of pressure rise of gaseous epoxypropane/air mixtures with volume fraction appear similar. When the volume fraction of gaseous epoxypropane lies in the range 3.5–7%, the combustion pressure and temperature and the rate of pressure rise of gaseous epoxypropane/air mixtures increase with the volume fraction, while in the range 7–30% these parameters decrease with the volume fraction. The rate of temperature rise of gaseous epoxypropane/air mixtures shows a slightly different trend. It reaches the highest value at a volume fraction of 10%. The combustion pressure and temperature of gaseous epoxypropane/air mixtures reach their highest values near the lower flammability limit, which is in marked contrast to previous results on gaseous nitromethane/air mixtures.

1. Introduction

Epoxypropane is an energetic material with a wide variety of applications, which include its use as a solvent for chemical processing and analysis, and as a high-performance fuel for internal combustion engines and pulsed detonation engines.

At atmospheric pressure and room temperature, epoxypropane is liquid. When it is used, liquid epoxypropane will evaporate into the air and mix with air to form flammable gaseous epoxypropane/air mixtures. The performance of gaseous epoxypropane/air mixtures as fuel includes the minimum ignition energy (MIE) and the explosion characteristic parameters. The effect of an accident is directly related to the explosion action described by such parameters as combustion pressure and combustion temperature. While the values of combustion parameters of gaseous epoxypropane/air mixtures are essential for safe and reliable operation, they are nevertheless hardly available in the literature.

Knowledge of the characteristics of the ignition and explosion of gaseous epoxypropane/air mixtures is an important prerequisite for proper usage. Although a great deal of research effort has been directed towards determining the combustion parameters of flammable gases and their MIEs [1–9], unfortunately, few researchers have paid attention to the combustion behavior of mixtures of gaseous epoxypropane and air.

The phenomena of gas explosions have been studied for many years [10,11]. Past experiences have shown that it is very important to collect accurate experimental data in order to clarify their mechanisms. Consequently, in this work, we have used an ignition energy measurement system consisting of a 5 L explosion vessel, a

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transient pressure measurement sub-system, and a transient temperature measurement sub-system [12]. Through a series of experiments carried out in this system, the influence of the concentration of gaseous epoxypropane on the combustion pressure and temperature and on the rates of combustion pressure rise and combustion temperature rise (corresponding to the slopes of the combustion pressure wave front and the combustion temperature wave front with time) have been analyzed and discussed, and the MIEs of gaseous epoxypropane/air mixtures with different concentrations have been studied.

2. Experimental apparatus and procedures

2.1. General

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, as shown in Fig. 1. Experiments were performed in a cylinder explosion 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 1 mm. The electrode diameter used in the experiments was 1 mm. A spark gap of 1 mm was used so that a lower ignition energy could be applied. The spark energy and duration were monitored by means of an ignition energy measurement system.

2.2. Combustion pressure and temperature

Explosions were monitored by means of Kistler pressure gauges and a fast-response temperature transducer mounted on the wall of the experimental vessel. All results were stored through a data acquisition device. The transient temperature measurement subsystem was made up of two parts, hardware and software, of which the hardware part was composed of a thermocouple transducer, a signal conditioning module, a data acquisition card, a PXI chassis and controller, and so on. The data acquisition system was triggered by the control unit, and recorded pressure and temperature data individually at sampling frequencies of 1 MHz and 0.1 MHz.

2.3. Spark ignition energy

By means of a traditional igniting test, one can easily determine the ignition energy on the basis of the given capacitance and applied voltage through simple calculation. The traditional test, referred to as the simple method, follows the general relationship expressed as:

$$E = \frac{1}{2}CU^2 \tag{1}$$

where C is the capacitance of the capacitor, U is the voltage of the capacitor discharge, and E is the energy stored in the capacitor, which is traditionally regarded as the ignition energy.

If the temporal variation of voltage at both ends of an igniting bridge thread can be measured and recorded and so can the current, the accurate ignition energy can be obtained, which is given by the following equation:

$$E = \int_0^t u(t)i(t)\mathrm{d}t \tag{2}$$

Here, E, different from the value in Eq. (1), is an accurate ignition energy value, $u(t)$ is the voltage between the respective ends of the electric bridge thread, $i(t)$ is the current through the electric bridge, and t is the duration of the ignition process.

In the calculation of ignition energy, it is necessary to know the voltage–time history and the current–time history at both ends of the electric thread. In order to meet these requirements, it is necessary to establish a special measurement system. Consequently, in the developed ignition energy measure system, a high voltage sensor P6015A and a voltage sensor P6139A were used to measure the voltage time history and the current time history.

Although attempts to measure MIE by integrating the current/voltage product may be justified, the result still significantly depends on the choice of pulse shape, discharge gap, and even electrode material [13,14].

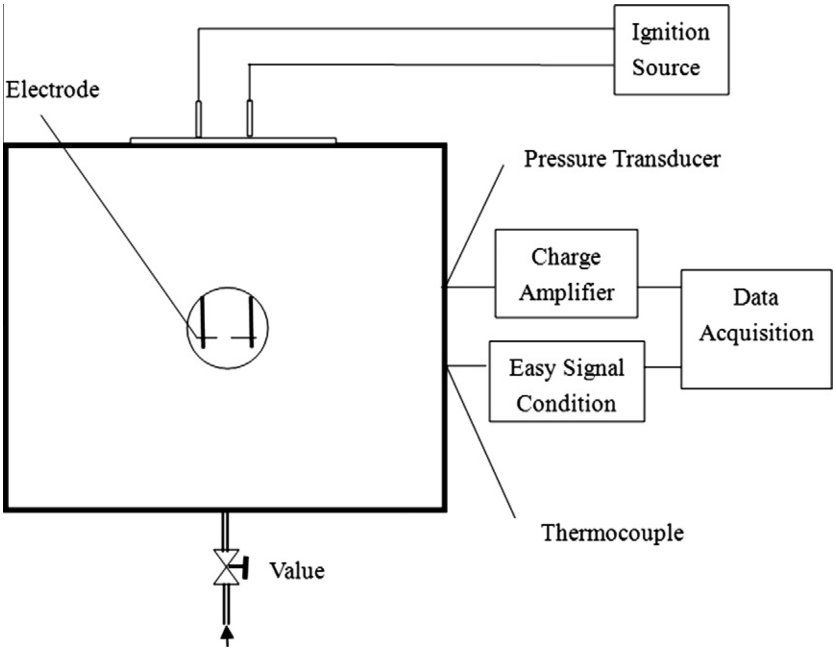

Fig. 1. Cylindrical vessel and experimental set-up.