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Short communication

Experimental study on the influence of the nitrogen concentration in the air on the minimum ignition energies of combustible powders due to electrostatic discharges

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A B S T R A C T

As a useful method of preventing dust explosions, nitrogen (N_2), an incombustible gas, has been applied to an explosive atmosphere. This paper is a report that quantitatively determines whether the minimum ignition energy of powder depends on the nitrogen (or oxygen) concentration in the air. Hartman vertical-tube apparatus and six sample powders were used in this study. The results show that the minimum ignition energies of all of the powders used in this study increased with increased amounts of N_2 in the air. However, the effects were different in all of the sample powders. We finally suggest that the N_2 concentration of 84% (or above) prevents dust explosions due to electrostatic discharges in the industrial process with the sample powders used in this experiment.

1. Introduction

Fine powders of several tens μm have been commonly used in industries such as food products and pharmaceuticals. The electrostatic charge build-up on fine powders is considered to be the product of frictional contact between two contacting materials. The electrostatic charge decreases production efficiency. In particular, electrostatic discharges (ESDs) caused by charge build-up on powders have been implicated in dust explosions or fires. Dust explosions often lead to labour casualties, property damage, and significant fiduciary penalties for companies.

To prevent dust explosions caused by ESD, the minimum ignition energy (MIE) of powders must be considered. MIE is a very important aspect of technical safety indices [BSI, 2002; IEC, 1994]. Many studies have been conducted on the MIE of powders. When determining the MIE, the oxygen concentration (21%) is fixed as normal air. On the other hand, as a useful method for preventing dust explosions, industries often try to reduce the oxygen (O_2) concentration in the air with nitrogen (N_2), an incombustible gas. Much research related to the minimum oxygen concentration (MOC) for combustion has been carried out. When determining the MOC, the ignition energy is plentifully fixed as 10 kJ [JIS, 2002]. Minimal research has been done on the correlation between the N_2 concentration in the air and the MIE-measured ESD as an ignition source [Ackroyd et al., 2011, Schwenzfeuer et al., 2001]. The present study focuses on quantitatively determining whether the MIE of powder depends on the N_2 (or O_2) concentration in the air. A primary objective of this paper is to communicate new, necessary information on ESD risk assessments that will be important to individuals working in the area of accident prevention and mitigation.

2. Experimental

2.1. MIE apparatus and method

The Hartman vertical-tube (1.2 L) apparatus (MIKE-3) is shown in Fig. 1, with only minor changes to the standard method and the gas mixture (O_2/N_2) supply part. The control range of the dust concentrations of the MIE apparatus used in this study is from 0.5 kg/m^3 to 1.5 kg/m^3. The energy of the electrostatic spark is varied by changing the capacitance of the capacitor and the applied

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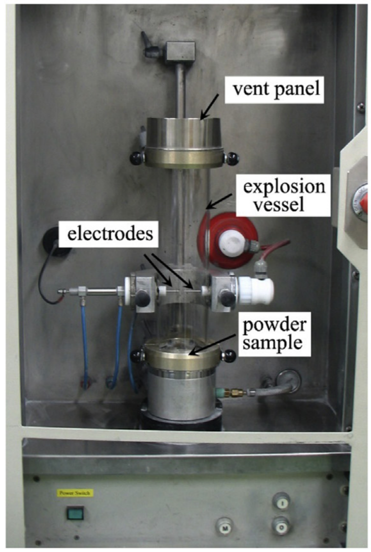
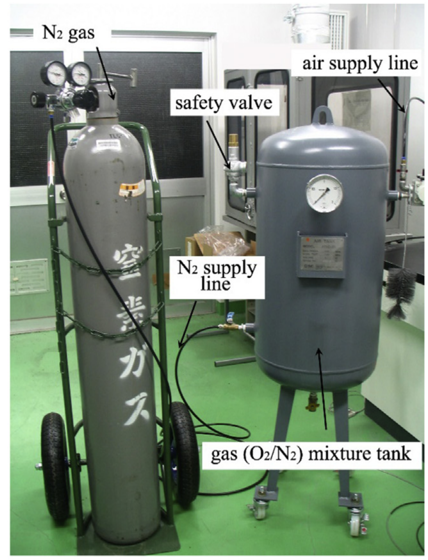


(a) Ignition device part



(b) gas mixture (O2/N2) supply part

Fig. 1. The MIE measurement apparatus used in this study.

voltage in the discharge circuit. The dust is dispersed by means of air stored in the reservoir (70 kPa), which is suddenly released into the chamber using a solenoid control valve. For MIE measurements, an electrostatic spark was triggered under a discharge circuit consisting of the following:

(1) Electrode spacing: 6 mm
(2) Electrode diameter: 2 mm (sharp tips)
(3) Electrode material: tungsten
(4) Inductance in the discharge circuit: 0.94 mH

Discharge conditions can affect the MIE of powders [Yamaguma et al., 2011]. The discharge conditions in this paper were the same as outlined in previous papers [Choi et al. 2005; Choi et al. 2006]. The electrostatic spark energy value of the discharge is calculated from Eq. (1):

$$W = 0.5\,C \times V^2, \quad (1)$$

where W is the stored energy in joules (J), C is the total discharge capacitance in farads (F), and V is the voltage of the charged capacitor in volts (V).

The maximum electrostatic spark energy used in this study was 1000 mJ. Observations were made until the lowest possible energy at which the flame propagates through dust clouds was reached under constant testing conditions. In this experiment, ignition was considered to have occurred when the flame had propagated at least 10 cm away from the position where the electrostatic spark was first observed. In the explosion vent panel mounted on the explosion vessel roof, there are two holes that are 4 mm in diameter. One of them is used to fill up the explosion vessel with the desired gas mixture (O_2/N_2). The other is used to measure the oxygen concentration in the explosion vessel using the oxygen analyzer. The procedure for a routine test at a certain dust concentration is as follows:

a) Set the desired concentration of O_2 in a gas mixture tank by adjusting the pressure gauges for both the normal air and the N_2 supply lines.
b) Place the sample powder at the bottom inside the explosion vessel to be tested.
c) Fix the air tube, which is connected to a gas-mixing tank 5 cm away from the bottom of the explosion vessel, and fix the other air tube, which is connected to an oxygen analyzer 5 cm away from the top of the explosion vessel.
d) Fill an explosion vessel with the desired gas mixture (O_2/N_2).
e) Disperse sample powder by means of the desired gas mixture stored in the reservoir.
f) Trigger the electrostatic spark for igniting the dust.
g) If ignition is obtained, the test is carried out again after lowering the energy level. If ignition is not obtained, the test is repeated 10 times under the same conditions.

All tests were carried out at room temperature, 23 ± 5 °C, and a relative humidity of 45 ± 5% RH.

2.2. Sample powders

The powders used in this experiment were lycopodium, four kinds of polymer powders, and toner. Lycopodium (50% volume-average, *D*50: 31 μm) was prepared as recommended in International Electrotechnical Commission (IEC) standards for calibration ignition tests [IEC, 1994]. The four kinds of polymer powders -Polymer P_1 (*D*50: 13 μm), Polyester (*D*50: 40 μm), epoxy (*D*50: 36 μm), and Polymer P_2 (*D*50: 29 μm)- were widely used in chemical industries and coating processes. Toner (*D*50: 8 μm) is a powder used in laser printers and photocopiers to form the printed text and images on paper. It should be noted here that detailed information about some of Polymers P_1 and P_2 and the toner cannot be given since the companies providing the powder samples wish to remain anonymous. The particle size of the powder was determined using a laser diffraction system (Nikkiso Co., Ltd., LDSA-1400A). Before any tests were carried out, the powder sample was dried up in a desiccator at 23 °C ± 5 °C for 24 h.

3. Results and discussion

Fig. 2 shows the ignition energy as a function of the dust concentration of each sample powder with the different O_2/N_2 ratios of