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Inerting of magnesium dust cloud with Ar, N_2 and CO_2

G. Li*, C.M. Yuan, Y. Fu, Y.P. Zhong, B.Z. Chen

Fire & Explosion Protection Laboratory, Northeastern University, Wenhua Road, Heping District, Shenyang, Liaoning 110004, China

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ABSTRACT

Experiments were conducted on the inerting of magnesium dust with N_2, CO_2, and Ar. Comparing the maximum explosion pressure, maximum rate of pressure rise, and limiting oxygen concentration with different inertants, it was determined that Ar is not the best inert gas under all conditions as commonly believed. N_2 was more effective than Ar as an inertant. CO_2 provided more inerting effect than either Ar and N_2 in low magnesium dust concentrations, although explosibility was increased at higher dust concentrations. Both N_2 and CO_2 as inerting agents showed higher LOC values than Ar. These results indicated that N_2 is a more economical inerting gas than Ar for the tested coarse magnesium dust.

1. Introduction

Preventing magnesium or aluminum dust explosions has been the subject of research for many years. Dust explosion hazard can be avoided by using wet grinding to generate fine aluminum dust and collecting particles as a slurry [1]. Unlike aluminum, however, magnesium reacts violently with water. Thus, production of super fine magnesium dust remains a challenge.

The minimum ignition energy (MIE) for very fine magnesium dust (<2 mJ) is as low as certain combustible gas mixtures [2], and thus is readily ignited. In addition, the explosion severity $[(dP/dt)_m, P_m]$ of fine magnesium dust can be extremely high, exceeding the effective range of explosion venting technology [3]. Explosion prevention is thus the only practical option when handling magnesium dust.

When the MIE is less than 10 mJ, preventing dust explosions solely by avoiding ignition sources becomes impossible [4]. For this reason, inerting technology has been widely recommended in handbooks, standards, and guidelines as the preferred means of preventing magnesium dust explosions [5–7].

The gases commonly used for inerting hazardous dusts are nitrogen, carbon dioxide, water vapor, and rare gases and shall have a LOC determined by test to be appropriate to the inerting gas. Selecting a suitable gas depends on cost, availability, and its reactivity with dust. Light alkaline metals such as magnesium and aluminum react with nitrogen and even with carbon dioxide under certain conditions as follows:

$$3Mg(s) + N_2(g) = Mg_3N_2(s) + Q$$

$$2Mg(s) + CO_2(g) = 2MgO(s) + C(g) + Q$$

$$2Al(s) + N_2(g) = 2AlN(s) + Q$$

Based on these theoretical reaction equations, nitrogen and carbon dioxide are not expected to provide explosion protection for aluminum and magnesium dust [5,6,8]. However, these chemical reactions can only occur at higher initial temperatures. Magnesium, for example, reacts with nitrogen at temperatures exceeding 300 °C [9]. When synthesizing magnesium nitride by self-combustion, the magnesium powder must be induced by ignition of some Ti at nitrogen atmosphere initially [10]. In addition, Going et al. [11] reported an LOC value of 8.5% by volume for aluminum dust diluted with nitrogen. Nifuku et al. [12] also found that minimum oxygen concentrations producing a dust explosion were about 10% by volume for aluminum and about 8% by volume for magnesium with nitrogen as the dilutant. Thus, it seems that nitrogen and carbon dioxide may still have potential as inerting agents.

Results on the inerting of magnesium or aluminum using inert solid powders such as MgO, CaO, and $CaCO_3$ have been reported [12,13]. Unfortunately inerting of magnesium with gas is not commonly practised. This work aims to investigate the inerting of magnesium dust cloud and to compare the parameters of explosion severity $[P_m, (dp/dt)_m]$ and LOC for the inertant gases: nitrogen, carbon dioxide, and argon.

* Corresponding author. Tel.: +86 24 83681830; fax: +86 24 83681483.
E-mail address: ligang@mail.neu.edu.cn (G. Li).

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Table 1
Physical parameters of a magnesium dust sample.

	Particle size distribution					Specific area ($m^2\ cm^3$)	Degree of activity (vol%)
	D_3[a]	D_{10}	D_{50}	D_{90}	D_{97}		
Diameter (μm)	18	26	47	76	94	0.145	98.62

[a] D_x denotes the particle diameter at which x percent of the particle mass has smaller diameters and $100 - x$ percent has larger, and that the figures in the line below are the corresponding particle diameters in micrometers.

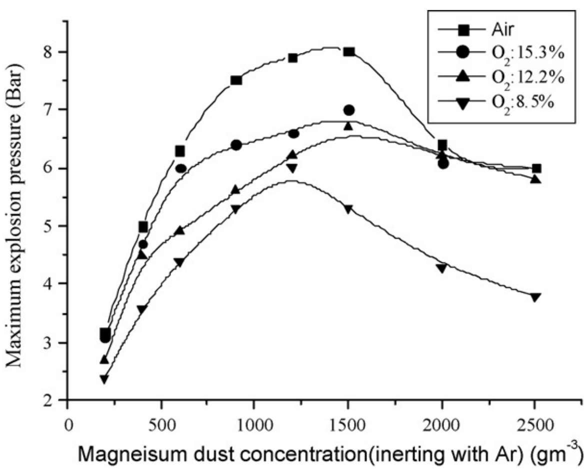

Fig. 1. Effect of magnesium dust concentration on P_m using Ar as inertant.

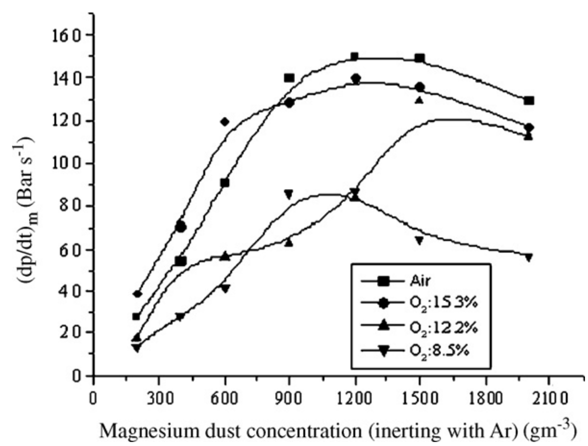

Fig. 2. Effect of magnesium dust concentration on $(dp/dt)_m$ using Ar as inertant.

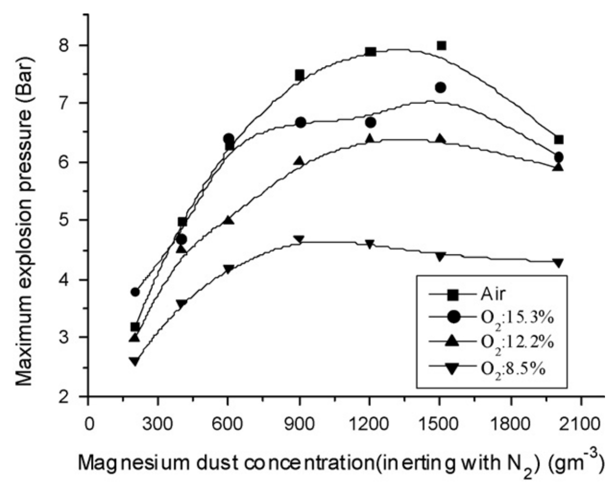

Fig. 3. Effect of magnesium dust concentration on P_m using nitrogen as inertant.

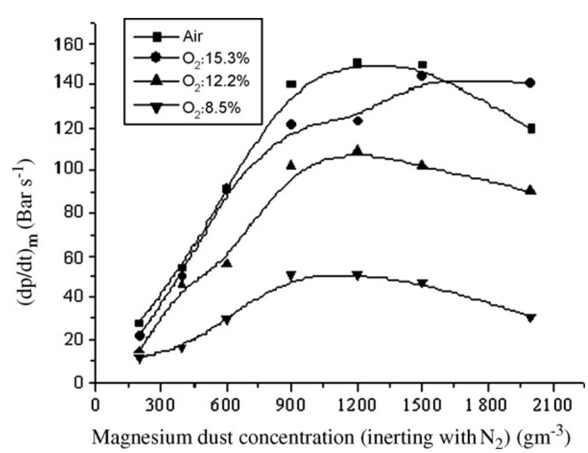

Fig. 4. Effect of magnesium dust concentration on $(dp/dt)_m$ using nitrogen as inertant.

2. Sample dust and experimental procedures

Sample magnesium dust is a commercial product manufactured using an atomization method [2]. The physical parameters of the sample are shown in Table 1.

Experiments were conducted using a 20-L spherical apparatus (Siwek type) with 8.5, 12.2, and 15.0% by volume oxygen concentration. The atmosphere of the 20-L vessel is prepared by partial pressure method. The vessel was first evacuated to a value corresponding to the determined oxygen concentration and then brought to atmospheric pressure by addition of the inert gas. The dust storage reservoir was pressurized to 2.0 bar (g) with a dry mixture of the inertant gas and oxygen at the experimental concentration values. Before dispersing the dust, the chamber was evacuated again to −0.6 bar (g), thus ensuring equivalent oxygen concentrations between the mixed gas in the chamber and the dispersing gas.

Ignition sources were electrically activated chemical ignitors composed of zirconium, barium nitrate, and barium peroxide at 40, 30, and 30% by mass, respectively. When testing the explosion severity parameters of P_m and $(dP/dt)_m$ 10-kJ ignitors were used. Ignitors with 2 kJ were used for LOC testing to avoid overdriving the explosion.

3. Results and discussion

3.1. Explosion severity parameters

For each inertant gas, the dust concentration varied from 200 gm^{-3} to the value at which P_m or $(dp/dt)_m$ began to decrease. P_m and $(dp/dt)_m$ for the three inertant agents are shown in Figs. 1–6. In order to compare the inerting effect the corresponding values tested in air condition (without inerting) was also illustrated.

With argon as the inerting agent, P_m values in oxygen concentrations of 15.3, 12.2, and 8.5% were lower than in ambient air conditions. Values of $(dp/dt)_m$ were somewhat larger than in ambient air when oxygen concentration was 15.3% and dust con-

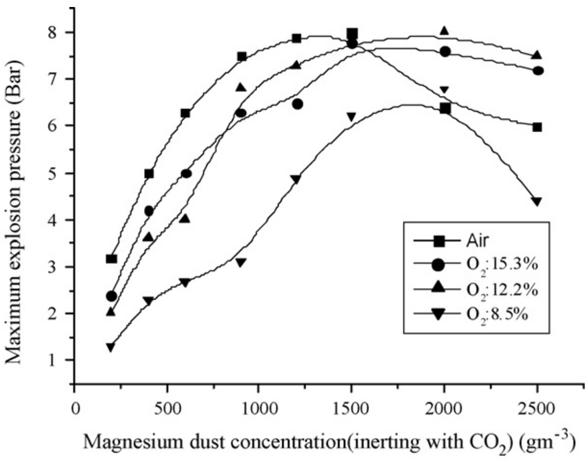

Fig. 5. Effect of magnesium dust concentration on P_{max} using carbon dioxide as inertant.

centration was below 800 g m^{-3}. All other experimental treatments showed $(dp/dt)_m$ values lower than under ambient air. From the P_m and $(dp/dt)_m$ point of view the inerting effect of argon was significant only when the oxygen concentration was below 8.5% and the magnesium dust concentration was greater than 1200 g m^{-3}.

With nitrogen as the inertant, P_m values were generally lower than in ambient air except at the lowest dust concentration of 200 g m^{-3} in Fig. 3. Oxygen at 8.5% yielded a lower maximum explosion pressure than when argon was used as inertant. When oxygen concentration was greater than 12.2%, its inerting effect was similar to that of argon. However $(dp/dt)_m$ values with nitrogen as inertant did not decrease as dust concentration increased at oxygen concentration of 15.3% in Fig. 4, in contrast to ambient air or with argon as the inerting agent. This is because nitrogen enhanced the oxidizing reaction of magnesium dust.

With carbon dioxide as the inertant gas, P_m was smaller than in ambient air when the dust concentration was below 1500 g m^{-3}. Even with an oxygen concentration of 8.5%, the P_m value was larger than that in air at a dust concentration of 2000 g m^{-3}, though it began to decline at higher dust concentrations. It means carbon dioxide can enhance the reaction more violently than nitrogen at higher magnesium dust concentration. Except when oxygen concentration was greater than 15.3% and dust concentration exceeded 2000 g m^{-3} $(dp/dt)_m$ values were lower than in ambient air.

In order to compare the inerting effect of the three gases, the P_m values at different magnesium dust concentrations but equivalent oxygen concentrations are shown in Figs. 7–9. At higher oxygen concentrations up to 15.3% (Fig. 7), the inerting effect of argon and nitrogen were similar for all dust concentrations. Compared to ambient air, the inerting effect of both inertant gases was only significant at dust concentrations between 600 and 2000 g m^{-3}. At dust concentrations below 1200 g m^{-3}, the inerting effect of carbon dioxide was greater than that of argon or nitrogen. This

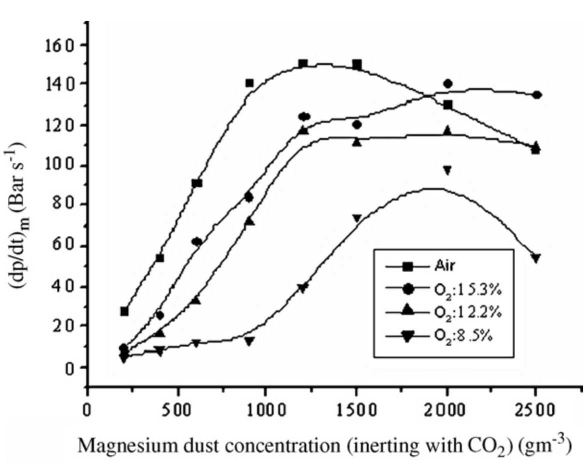

Fig. 6. Effect of magnesium dust concentration on $(dp/dt)_m$ using carbon dioxide as inertant.

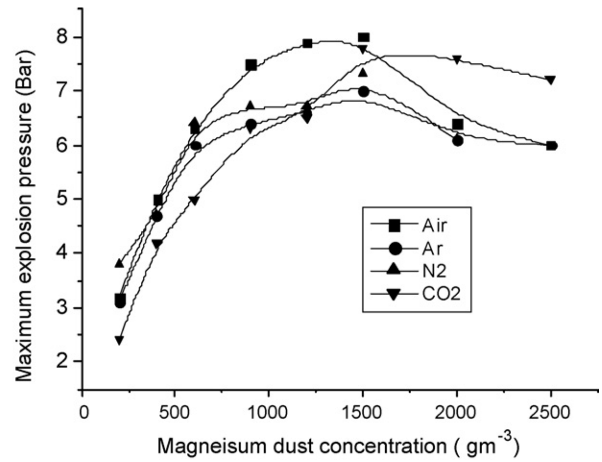

Fig. 7. Effect of magnesium dust concentration on P_m with oxygen at 15.3% by vol.

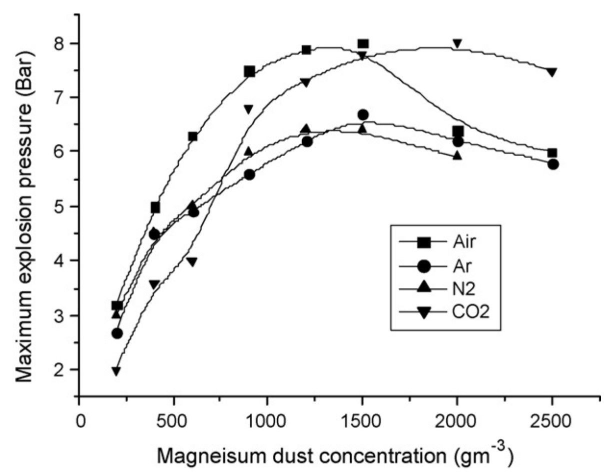

Fig. 8. Effect of magnesium dust concentration on P_m with oxygen at 12.2% by vol.

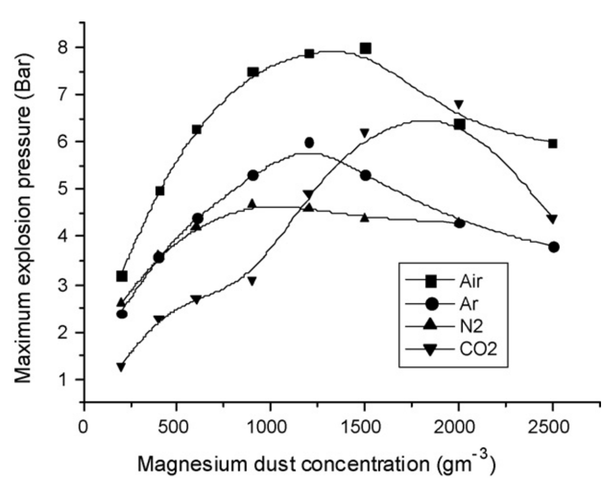

Fig. 9. Effect of magnesium dust concentration on P_m with oxygen at 8.5% by vol.

Table 2
Molar thermal capacity of inerting agent (273 K).

Inerting agent	Argon	Nitrogen	Carbon dioxide
Molar specific heat capacity (J K mol^{-1})	20.72	28.78	37.23

Table 3
LOC for different inerting agents.

Inerting agent	Argon	Nitrogen	Carbon dioxide
LOC (vol%)	4.0	6.8	5.5

could be due to the larger molar specific heat capacity of carbon dioxide compared to argon and nitrogen, as shown in Table 2. However, when dust concentrations surpassed 1200 g m^{-3}, carbon dioxide showed no inerting effect and also increased the maximum explosion pressure value compared to ambient air. When oxygen concentration was reduced to 12.2% (Fig. 8), the inerting effect of argon and nitrogen became significant at dust concentrations as low as 400 g m^{-3}. For carbon dioxide the inerting trend was similar to that observed for an oxygen concentration of 15.3%.

When oxygen concentration was decreased to 8.5% (Fig. 9), the inerting effect of argon and nitrogen became significant at all dust concentrations. For carbon dioxide, the inerting effect was also significant except near dust concentrations of 2000 g m^{-3}.

3.2. LOC

In order to determine the LOC for magnesium dust, the dust concentration was varied from 50 g m^{-3} (lower explosible concentration) to 450 g m^{-3} (stoichiometric concentration). When the over pressure surpassed 0.5 bar, an explosion was considered to occur [14]. Based on this evaluation criterion, LOC values determined using a 20-L apparatus for argon, nitrogen, and carbon dioxide are shown in Table 3. Surprisingly, nitrogen as inerting agent yielded the highest LOC. These results indicate that when using nitrogen or carbon dioxide as inertant, oxygen concentrations lower than 6.8 and 5.5%, respectively, will not support a flame propagation in the cloud of the tested magnesium dust. Though nitrogen and carbon dioxide both can react with magnesium, it may be that the energy generated during the initial reaction of magnesium and oxygen in the presence of either of these inertants is too low to trigger the reaction of magnesium and nitrogen or carbon dioxide. Meanwhile nitrogen and carbon dioxide can consume more energy than oxygen for the same temperature increasement. In addition, the consumed nitrogen or carbon dioxide counteracted some expanding effect of the heated gases. It should be noted that LOC values for dusts of a particular chemical composition could also differ with variations of physical properties such as particle size, shape, and surface characteristics, also differ with the ignition energy. When the above LOC values are put into practice sufficient safety margin should be kept.

These results reveal the speciality of the inerting effect of nitrogen and carbon dioxide on the magnesium dusts. For the tested magnesium dust nitrogen and carbon dioxide presented inerting effect at certain oxygen dust concentration.

4. Conclusions

It's a generally accepted idea that nitrogen and carbon dioxide cannot be used as inerting agents for magnesium dust explosion prevention. These results, however, indicate that nitrogen has an inerting effect similar to argon when the oxygen concentration of the inerted atmosphere is greater than 12.2% by volume. The inerting effect is not significant for both of argon and nitrogen when dust concentration is either relatively low or quite high, and when the oxygen concentration of the inerted atmosphere is relatively high. The lower the oxygen concentration, the wider the dust concentration range over which a significant inerting effect is observed. Compared with argon and nitrogen, carbon dioxide may be more effective as an inertant at low dust concentration, but can intensify explosion and increase maximum explosion pressure compared to ambient air. When decreasing the oxygen concentration to 8.5%, the inerting effects of all three inerting agents became significant.

LOC is the lowest oxygen concentration below which a flame cannot propagate through a given dust cloud. The LOC values generated in this study indicate that nitrogen and carbon dioxide can be economical choices as inerting agents for the tested coarse magnesium dusts for certain scope of oxygen and dust concentration.

The limitation and practicality of these results will need further experimentation with different particle sizes of magnesium dust and in larger test vessel like 1 m^3 to characterize the inerting effect of nitrogen and carbon dioxide systematically.

Acknowledgement

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