Study on the Influence of Magnetic Metal Materials on Inhibit Gas Explosion

Shang-Yong Zhou, Shou-Tao Hu, Jian-Cun Gao, Le Wang, and Xu Sun

***Abstract*—In order to study the effect of magnetic metal materials on gas explosion pressure the closed explosion experiments were carried out with an independently designed explosion transient pressure test device, the explosion tests of 12% volume concentration methane-air, 5% volume concentration propane-air, and 8% volume concentration propane were carried out under the condition of installing copper, aluminum, nickel and iron metal materials. The transient pressure changes were measured and compared. The results of experiments show that: After the installing of the metal material, the peak value of the explosion pressure of the explosion is significantly reduced, indicating that the installing metal material can effectively inhibit the explosion of the combustible gas. It also can be seen that the magnetic metal materials nickel and iron have better inhibition performance than the non-magnetic metal material aluminum and copper in the gas explosion. And with the increase of the molecular weight and concentration of combustible gas, the explosion inhibition performance of magnetic metal materials become more obviously. The magnetic field effect of the magnetic metal can effectively affect the motion law of the free radicals during the explosion reaction, thus affecting the release of the explosive reaction energy.**

***Index Terms*—Magnetic, metal material, explosion pressure, transient pressure.**

I. Introduction

Combustible gases such as methane and propane are commonly used in chemical production and have significant fire and explosion risks [1], [2]. It is of great significance to carry out theoretical and experimental research on the restraining factors of gas explosion and seek for effective ways to reduce accident losses.

Many scholars have studied the explosive properties of flammable gas [3]-[8]. gas explosion is accomplished by free radicals through a multi-step elementary reaction [9]. During the explosion, many intermediate products and transient products such as molecules, radicals, ions, electrons, etc. are produced. The magnetic field has a certain influence on the free radical motion [10]. The chemical reaction system and the movement of the unpaired electrons of the reactant are affected by the magnetic field, so that the entropy of the reaction system changes, which in turn affects the progress of the chemical reaction. Many scholars have carried out research on the influence of electromagnetic fields on the flame propagation process. The research shows that the magnetic field effect has obvious influence on the flame propagation speed, flame shape and direction of motion during flame propagation [11]-[19]. However, there are very few references to explain the influence of magnetic materials on the explosive strength of premixed gases.

In this article, a new experimental system was designed and constructed to study the influence of magnetic metal materials on inhibit gas explosion. In this system, explosion tests of different premixed combustible gases were carried out by installing magnetic materials and non-magnetic materials in the explosion tank, and the influence of the magnetic properties of the metal materials on the explosive strength of the premixed combustible gas and the influence of the magnetic field effect of magnetic metal on the free radical reaction during the explosion reaction was studied.

II. Experimental

The experimental system consists of an ignition device, an explosion tank, and a transient pressure test system. The schematic diagram of the experimental system is shown in Fig 1. The transient pressure test system has 16 acquisition channels. For multi-channel sampling, the sampling frequency of each channel can be set by itself, and the maximum acquisition frequency is 15000 Hz. The ignition device consists of an EPT-7 high-energy ignition table and an ignition head. The ignition energy of the ignition table has three levels, 200mJ, 500mJ and 700mJ.

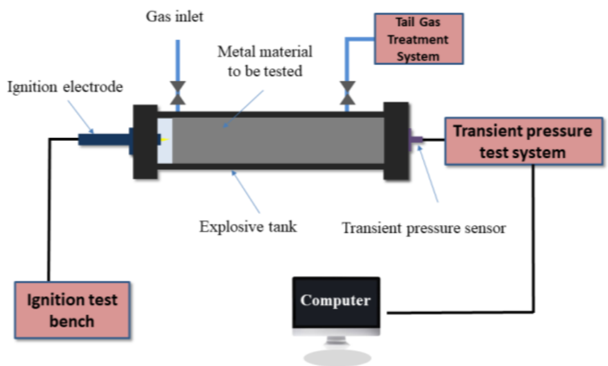

Fig. 1. Schematic diagram of the experimental device.

The experimental procedure is as follows:

(1) installation of metal materials. One of aluminum wire, copper wire, nickel wire and iron wire is installed in the explosion tank. The metal material having a diameter of 0.2

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mm and a surface area of 0.119 m^2 are respectively rolled into a cylindrical shape having a diameter slightly larger than the inner diameter of the explosion pipe, wherein the copper wire and the aluminum wire are non-magnetic metal materials, nickel wire and the iron wire are magnetic metal materials. Installing material parameters are shown in Tab 1. In order to eliminate the influence of dirt on the metal wire surface on the experimental results, the wire was washed with ethanol for 30 min and then five times using water under ultrasound to clean the surface and then placed in an high vacuum drying oven at 100 ℃ at least for 5 hours for drying before testing. Reserve 5% volume space at the upper end of the explosion pipe for the ignition device to ignite. The remaining space of the test vessel is uniformly installed with metal material. The cover is fixed to the can body.

(2) Check the airtightness of the device. Inject air into the pipe and apply the soapy water to the interface. If there is bubbling, it means that the airtightness is not tight, sealing the leaking place and it is continuously applied with soapy water until there is no bubbling.

(3) Ignition and data collection. After the device is airtight, the premixed combustible gas is injected into the explosion tank, the transient pressure test system is turned on and the sensor connection state is detected. Connect the pressure sensor intact, set the ignition energy of the ignition test bench after the data acquisition is normal, click on the discharge switch and observe the waveform changes on the test software. After the test is completed, the metal material is taken out and placed in an ultrasonic cleaner for cleaning for the next time. Experimental parameters are shown in Table II.

TABLE I: INSTALLING METAL MATERIAL PARAMETER TABLE

Type of metal material	ρ(g/m^3)	d (mm)	s(m^2)	m(g)
Cu	8.96	0.2	0.119	53.28
Al	2.70	0.2	0.119	16.06
Ni	8.904	0.2	0.119	58.29
Fe	7.784	0.2	0.119	46.29

TABLE II: EXPERIMENTAL PARAMETER TABLE

Serial number	Combustible gas type	Metal materials(one of them)	Ignition energy(mJ)
1	12%CH_3	Al, Cu, Ni, Fe	700mJ
2	5%C_3H_8	Al, Cu, Ni, Fe	700mJ
3	8%C_3H_8	Al, Cu, Ni, Fe	700mJ

III. RESULTS AND DISCUSSION

A. 12% Methane-Air Premixed Gas Explosion Test

12% volume concentration methane-air mixture explosion test with different magnetic metal materials. Four kinds of wires with a diameter of 0.2mm and a surface area of 0.119m2 were installed in the explosion tank, and a gas explosion experiment was carried out, and the explosion pressure was tested. In the explosion test of 12% volume concentration methane-air mixture, the transient explosion pressure-time curve of installed aluminum wire and empty can is shown in Fig. 2. The explosion pressure-time curve for loading four kinds of wires is shown in Fig 3.

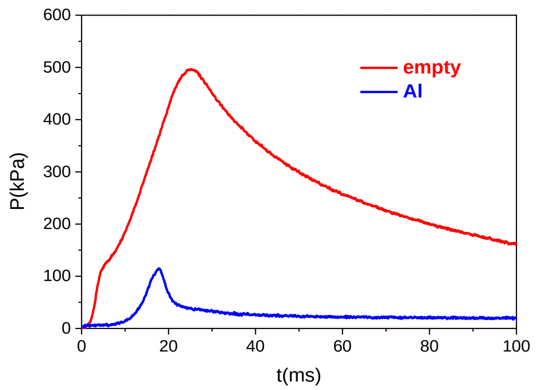

Fig. 2. Explosion transient pressure-time curve of 12% volume concentration methane-air mixture installed with aluminum wire and empty tank.

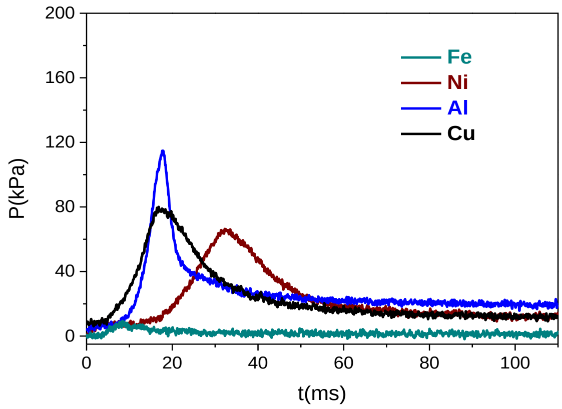

Fig. 3. Explosion transient pressure-time curve of 12% volume concentration methane-air mixture installed with different metal materials.

It can be seen from Fig 2 that: in the 12% methane-air mixture explosion, the explosive transient pressure is significantly reduced after installing the metal material, so the metal materials have good explosion inhibition in methane-air mixture explosion. In the explosion test of 12% volume concentration methane-air mixture installed with different metal materials, the peak value of the explosion pressure about different metal materials are different, Pmax(Al)>Pmax(Cu)> Pmax(Ni)>Pmax(Fe), The peak pressure of aluminum is 114.87 kPa, the copper is 87.11 kPa, the nickel is 70.24 kPa, and the iron is 9.41 kPa. The peak value of the explosion pressure after installing the magnetic metal material is more significantly lower than the peak value of the non-magnetic metal material, iron is the most obvious, and nickel is not much different from copper.

B. 5% Propane-Air Premixed Gas Explosion Test

5% volume concentration propane -air mixture explosion test with different magnetic metal materials. In the 5% propane-air explosion test, the peak value of the explosion pressure after installing the aluminum material was significantly lower than that of the uninstalled metal material, and the experimental results are shown in Fig. 4: the peak value of the explosion pressure are different after installed different metal materials, Pmax(Al)>Pmax(Cu)> Pmax(Ni)>Pmax(Fe). The peak pressure of aluminum is 171.85 kPa, the copper is 157.47 kPa, the Ni is 134.36 kPa, and the iron is 98.1 kPa. After installing the magnetic metal material, the peak value of the explosion pressure after installing the magnetic metal material is more significantly lower than the peak value of the non-magnetic metal material.

The experimental results are shown in Fig. 5.

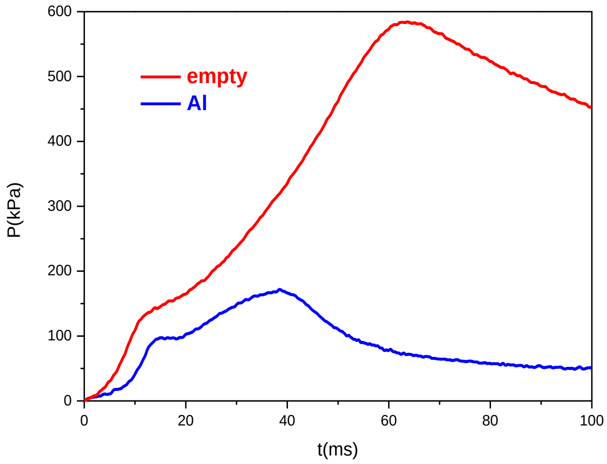

Fig. 4. Explosion transient pressure-time curve of 5% volume concentration propane-air mixture installed with aluminum wire and empty tank.

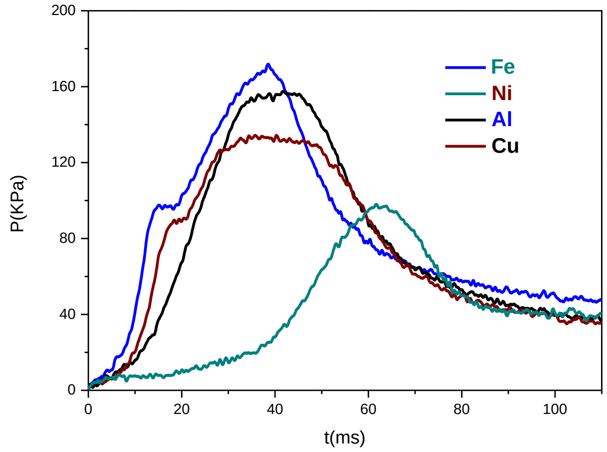

Fig. 5. Explosion transient pressure-time curve of 5% volume concentration propane-air mixture installed with different metal materials.

C. 3 8% Propane-Air Premixed Gas Explosion Test

8% volume concentration propane -air mixture explosion test with different magnetic metal materials. The transient pressure-time curve of the 8% volume concentration propane-air mixture installed with aluminum wire and empty can is shown in Fig. 6. The explosion pressure-time curve in the case of installing four kinds of metal wires is shown in Fig. 7.

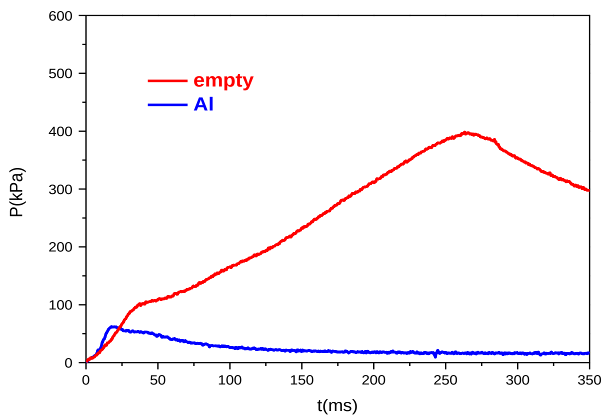

Fig 6. Explosion transient pressure-time curve of 8% volume concentration propane-air mixture installed with aluminum wire and empty tank.

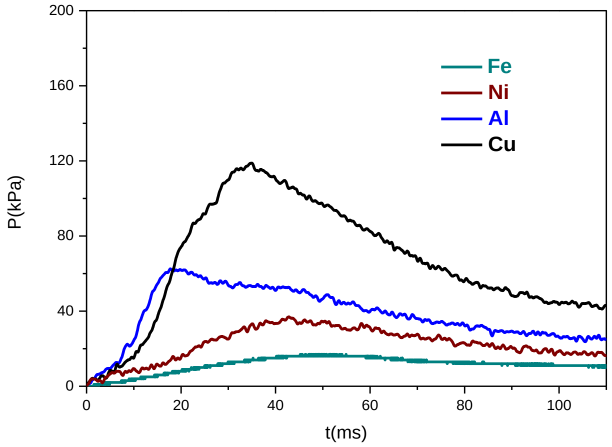

Fig. 7. Explosion transient pressure-time curve of 8% volume concentration propane-air mixture installed with different metal materials.

It can be seen from Fig. 6 and Fig. 7 that: In the 8% volume concentration propane-air mixture explosion test, the peak value of the explosion pressure after installing the aluminum material was significantly lower than that of the uninstalled metal material. The peak value of the explosion pressure about different metal materials are different, Pmax(Cu)>Pmax(Al)> Pmax(Ni)>Pmax(Fe). The peak pressure of aluminum is 62.54 kPa, the copper is 118.84 kPa, the nickel is 36.94 kPa, and the iron is 17 kPa. The peak value of the explosion pressure after installing the magnetic metal material is more significantly lower than the peak value of the non-magnetic metal material.

D. Discussion

By calculating the explosion pressure data in the empty tank and the installing metal material, we can get: in the 12% methane-air mixture explosion test, the inhibition rates of aluminum, copper, nickel, iron are 76.88%, 82.46%, 85.86% and 98.1%, in the 5% propane-air mixture explosion test, the inhibition rates of aluminum, copper, nickel, iron were 70.58%, 73.04%, 77.01% and 83.22%, in the 8% propane-air mixture explosion test, the inhibition rates of aluminum, copper, nickel, and iron are 84.31%, 70.18%, 90.73%, and 95.73%. The calculation results are shown in Fig. 8.

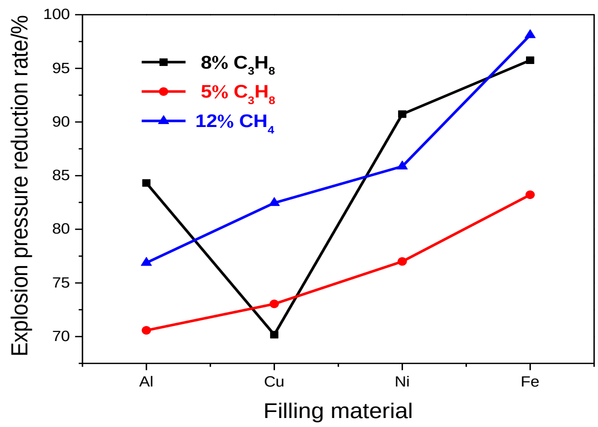

Fig. 8. Comparison of metal material explosion inhibition rate under different gases conditions.

It can be seen from the Fig.8 that: The explosion inhibition rate of nickel and iron is significantly greater than the explosion inhibition rate of aluminum and copper. This is because iron and nickel are magnetic metal material, aluminum and copper are non-magnetic metal material , the magnetic field effect of the magnetic metal material affects the motion law of the free radicals in the explosion reaction, thereby changing the reaction path of the combustible gas explosion, and finally leading to the difference in the energy released in the explosion reaction. in the explosion test of different gases, the same metal material has different explosion inhibition rates. Compared with the 12% volume concentration methane-air explosion test, in the 8% volume concentration propane-air explosion test, the phenomenon of that the magnetic material is better than non-magnetic material in explosion inhibition rates is more obvious. It is proved that as the molecular weight of the combustible gas increases the influence of the magnetic material on the explosion pressure is greater. Compared with the 5% volume concentration propane-air explosion test, in the 8% volume concentration propane-air explosion test, the phenomenon of that the magnetic material is better than non-magnetic material in explosion inhibition rates is more obvious. It is proved that as the concentration of the combustible gas increases the influence of the magnetic material on the explosion pressure is greater.

In the chain reaction of methane-air mixture, $\cdot OH$, $\cdot CH_3$ and $HCO\cdot$ determine the progress of gas explosion chain reaction. Radicals are paramagnetic particles, and magnetic metal materials affect the transport of these radicals. Magnetic metal materials affect the migration of these free radicals, leading to the early termination of the chain transfer process, which affects the release of methane gas explosion energy. In the chain reaction of propane-air mixture $\cdot C_3H_7$, $HCO\cdot$ determine the progress of the chain reaction. Compared with the chain reaction of methane, the molecular weight of the radical that determines the progress of the propane chain reaction is larger, and it is more conducive to the influence of magnetic materials on the radical motion. The magnetic material is more likely to affect the transfer process of the propane chain reaction. The probability of early termination of the reaction is greater. Compared to a propane-air mixture with a volume concentration of 5%, the 8% volume concentration propane-air mixture is more enriched with higher molecular weight radicals, so in the 8% volume concentration propane-air mixture explosion test, the effect of the magnetic material on the explosive energy release of the gas is more obvious.

IV. Conclusions

In a self-designed explosive testing device, the transient pressure of different gases installed with different magnetic metal materials was measured by a transient pressure testing system. The results show that:

a. Installing metal materials can effectively inhibit the explosion of combustible gas and greatly reduce the peak explosion pressure.

b. Explosion experiments with aluminum, copper, nickel, and iron wire carried out under 12% volume concentration methane-air, 5% volume concentration propane-air, and 8% volume concentration propane-air mixture respectively. It can be seen from the explosion transient pressure curve that the peak value of explosive pressure installed with nickel, iron is obviously lower than that of installed aluminum, copper. It is proved that the explosion inhibition performance of magnetic metal iron, nickel is better than that of non-magnetic metal aluminum, copper.

c. The experimental results of methane-air mixture explosion and propane-air mixture explosion show that: with the increase of the molecular weight of combustible gas, the effect of magnetic metals on the peak value of explosion transient pressure is more obvious. The phenomenon of that the magnetic material is better than non-magnetic material in explosion inhibition rates is more obvious.

d. The experimental results of 5% volume concentration propane-air mixture explosion and 8% volume concentration propane- air mixture explosion show that: with the increase of combustible gas concentration, the effect of magnetic metals on the peak value of explosion pressure is more obvious. The phenomenon of that the magnetic material is better than non-magnetic material in explosion inhibition rates is more obvious.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Shangyong Zhou, Le Wang, Xu Sun completed the experimental research work; Shoutao Hu, Shangyong Zhou completed the data analysis work; Shangyong Zhou, Jiancun Gao, Shoutao Hu completed the writing of the paper. all authors had approved the final version.

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