Development of an Alternative Flame Retardant Gas for Magnesium Melting Furnaces

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Abstract

JATCO uses sulfur hexafluoride (SF_6) as a flame-retardant gas in magnesium melting furnaces. SF_6 has an extremely high global warming potential; hence, its replacement with alternative gases is required to meet the carbon-neutral goal. This study reports the evaluation results of preliminary experiments on the adoption of an alternative flame-retardant gas.

1. Introduction

Owing to global environmental issues, it is essential to improve the fuel efficiency of automobiles. Transmissions must not only improve efficiency but also reduce weight. The conventional JATCO transmission case parts were composed of aluminum alloys. The new nine-speed automatic transmission for rear-wheel drive (RWD) vehicles (Fig. 1), for which mass production began in 2019, uses a magnesium (Mg) alloy for the transmission case to achieve a weight reduction of approximately 4 kg.

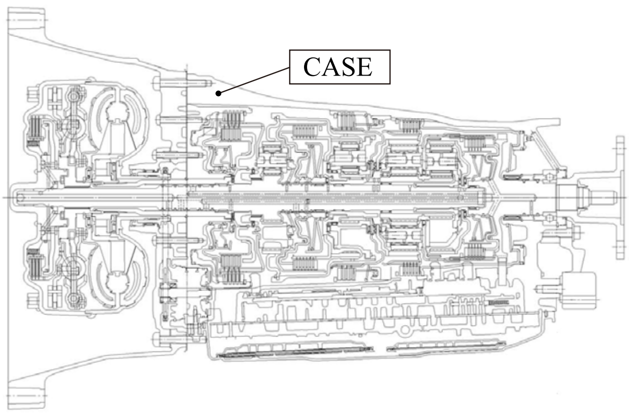

Fig. 1 9-speed automatic transmission for RWD vehicles

A die-casting line dedicated to Mg was constructed in conjunction with the production of a new nine-speed transmission case. The die-casting line consists of a Mg ingot feeder, melting furnace, die-casting machine, and trim press. The flame-retardant gas discussed in this study is used in a Mg melting furnace.

As Mg combusts spontaneously at temperatures $\geq 400°C$, it is necessary to prevent the combustion of molten metal at temperatures $\geq 600°C$ using a flame-retardant gas, such as sulfur hexafluoride (SF_6). However, SF_6 has been designated as a target of the Act on Promotion of Global Warming Countermeasures. SF_6 has a global warming potential (GWP) approximately 23,000 times that of CO_2. The Mg casting line of JATCO is one of the largest in Japan in terms of production weight, and SF_6 comprises 8% of the greenhouse gases emitted by JATCO (Fig. 2). Therefore, it is necessary to develop an alternative gas to SF_6 to achieve a 46% reduction (compared to FY2013) in greenhouse gas emissions by FY2028.

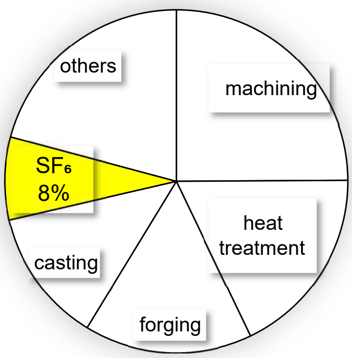

Fig. 2 Ratio of CO_2 emission

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2. Selection of alternative gases

Five potential alternative gases were selected as replacements for SF_6, as shown in Table 1[(1)]. Three factors were evaluated for gas selection: GWP, half-lethal concentration (LC50), and perfluorinated organic compounds (PFAS) regulation.

First, regarding gas (1) SO_2, even the presence of trace amounts in the air is a concern for human health as even a low LC50 value poses a high risk. Strict environmental standards for gas (1) have been established in Japan, restricting its adoption. However, gases (2)-(4) are expected to fall under PFAS regulations, and their use and production are expected to be banned in the future. As there were cases in which the production of gas was suspended owing to PFAS regulations, the adoption of gases (2)-(4) was discarded. Therefore, gas (5) trifluoroiodomethane (CF_3I) was selected as a substitute for SF_6. The GWP of CF_3I was 0.4 times that of CO_2, which is a significant improvement over the GWP of SF_6, which was 23,000 times that of CO_2. CF_3I has not been used as a flame-retardant gas for Mg; hence, preliminary experiments were necessary.

Table 1 Alternative gases

Alternative gases		GWP	LC50 (ppm)	PFAS Regulation Applicable	Practical Use for magnesium
(1)	SO_2	0	2,520	No	Yes
(2)	C_3F_6O	1	>100,000	Yes	Yes
(3)	HFC134	1,300	350,000	Yes	Yes
(4)	OHFC-1234ze	30	>100,000	Yes	Yes
(5)	CF_3I	0.4	>100,000	No	No

3. Experimental procedure

3.1 Evaluation method

The performance of flame-retardant gases must be evaluated based not only on their flame-retardant characteristics, but also on the potential generation of toxic gases due to chemical reactions in the furnace and their effect on casting quality. This study focuses on flame-retardant properties. Flame-retardant properties are often evaluated based on the binary value of whether a material burns. In this study, a quantitative evaluation method was investigated. As the combustion of Mg is the reaction $2Mg+O_2 \rightarrow 2MgO$, it was considered that the degree of combustion (flame-retardance) could be evaluated using the amount of magnesium oxide (MgO) generated. Therefore, the molten metal surface was divided into 20 sections, as shown in Fig. 3, and the presence of MgO was determined for each section. The percentage of MgO on the molten metal surface was considered as the MgO generation rate.

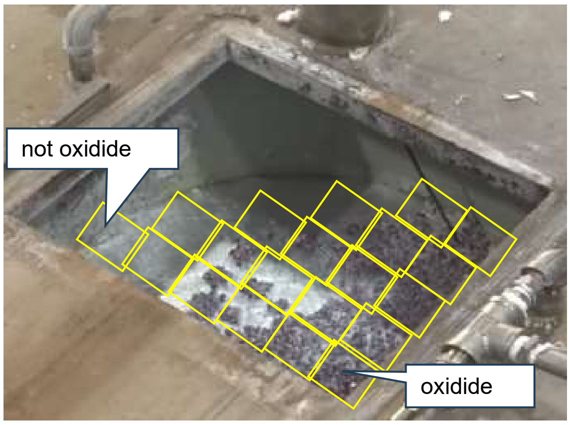

Fig. 3 Inflammability evaluation

3.2 Experimental conditions

Preliminary experiments were conducted in a 50 kg melting furnace owned by the Ibaraki Prefecture Industrial Technology Innovation Center (Fig. 4).

Fig. 4 Melting furnace for experiment

The flame-retardant gas was supplied to the molten surface using a carrier gas, such as N_2 or CO_2. When molten Mg reacted with CF_3I, magnesium fluoride (MgF_2) was formed on the molten metal surface (Fig. 5). The formation of the MgF_2 film impeded contact between oxygen and the molten metal, preventing combustion. The flame-retardant gas was thermally decomposed upon exposure to high temperatures in the furnace, and its performance degraded.

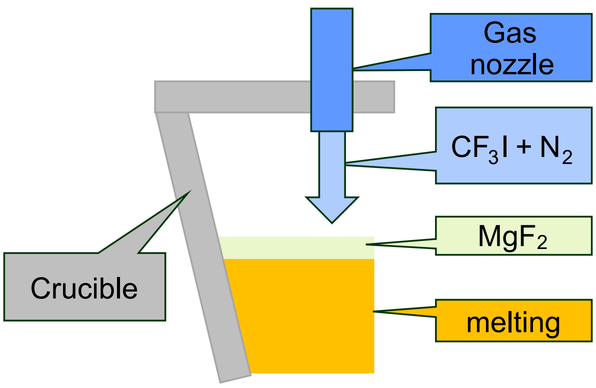

Fig. 5 Flame retardant film MgF_2

Therefore, it was considered that the amount (concentration) of the flame-retardant gas, carrier gas, and temperature of the molten metal affect the formation of flame-retardant films.[(2),(3)] Three levels of investigation were conducted for each factor to determine their degree of influence.

After setting the prescribed experimental conditions, such as the gas and molten metal temperatures, MgO was removed from the surface of the molten metal, and the molten metal was allowed to stand for 2 min. The rate of MgO generation on the surface was observed to evaluate the flame-retardant characteristics.

The experimental conditions for alternative gases were as follows:

(i) Melting furnace: 50 kg melting furnace.
(ii) Mg alloy material: AS31.
(iii) Flame-retardant gas: CF_3I.
(iv) Concentrations of flame-retardant gas: 250, 500, and 1,000 ppm
(v) Carrier gases: N_2, $N_2 + CO_2$ mixture, and CO_2.
(vi) Molten-metal temperature: Base - 20°C, base (temperature of the actual equipment), and base + 20°C.
(vii) Furnace lid: Open.
(viii) Duration of experiment: 2 min.

4. Results

Experiments conducted using actual equipment under actual production conditions (SF_6) resulted in an MgO generation rate of 40%. This value was set as the target value for CF_3I.

The results of the tests on CF_3I are described below. First, the flame-retardant characteristics of the flame-retardant gas were evaluated at each concentration. Fig. 6 shows the results of the experiments conducted under conditions where the molten-metal temperature was the same as that of the actual equipment (base), the carrier gas was fixed as N_2, and the CF_3I concentrations were 250, 500, and 1,000 ppm. It was found that the higher the CF_3I concentration, the higher the flame-retardance, and that a CF_3I concentration of 500 ppm resulted in flame-retardance that was almost equivalent to that of SF_6.

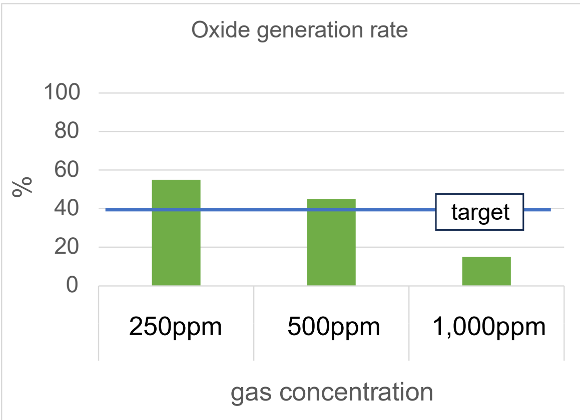

Fig. 6 Inflammability evaluation of gas concentration

Subsequently, the flame-retardant characteristics of each carrier gas were evaluated. Fig. 7 shows the results of the experiments conducted under the conditions of a 500 ppm CF_3I concentration, the same molten-metal temperature as that of the actual equipment (base), and three carrier gas types (N_2 only, a mixture of N_2 and CO_2, and CO_2 only). It was revealed that the CO_2-only condition resulted in a higher flame-retardance. However, under CO_2-only conditions, the toxic gas hydrogen fluoride (HF) was generated, which corroded the metals in the furnace. Therefore, a mixture of N_2 and CO_2 gases was used for further investigation.

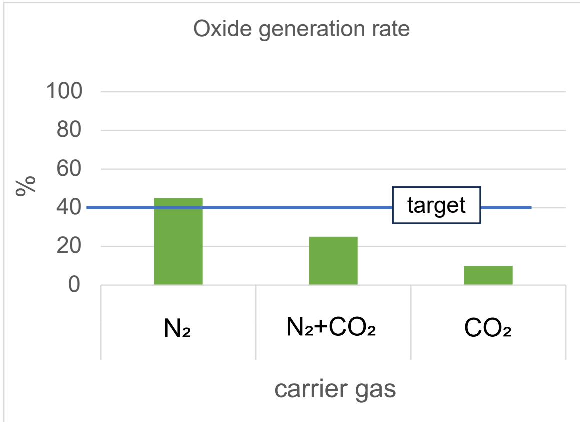

Fig. 7 Inflammability evaluation of carrier gases

Next, the flame-retardance was evaluated at different molten metal temperatures. Fig. 8 shows the results of the experiments conducted under the conditions of a flame-retardant gas concentration of 500 ppm, carrier gas of an N_2 + CO_2 mixture, and molten metal temperatures of base - 20 °C, base, and base + 20° C. The flame-retardant properties decreased at higher molten metal temperatures and increased at lower molten metal temperatures.

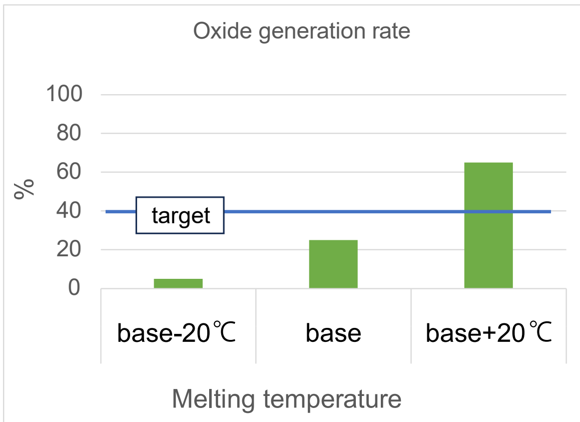

Fig. 8 Inflammability evaluation of melting temperature

5. Discussion

The experimental results are discussed below.

As for the effect of the CF_3I concentration, the flame-retardance improved with higher concentrations. This was because a sufficient amount of CF_3I was supplied to the molten metal surface, facilitating the formation of a flame-retardant film.

Regarding the effect of the carrier gas, flame-retardance improved with higher amounts of CO_2. This was because the specific gravity of CO_2 is higher than that of N_2, and CF_3I readily reached the molten metal surface before CF_3I thermally decomposed, which facilitated the formation of a flame-retardant film. However, when a CO_2-only carrier gas was used, HF was generated, and corrosion was observed on the metal parts in the furnace. Therefore, the amount of mixed CO_2 must be maintained at a level that does not generate HF. It was confirmed that when a mixture of N_2 and CO_2 gases was used at a specified ratio, the generated HF was lower than the environmental standard value.

With respect to the effect of the molten metal temperature, the flame-retardant properties decreased at higher molten metal temperatures. This was because CF_3I was pyrolyzed before reaching the molten metal surface, resulting in insufficient formation of the flame-retardant film. Although it is possible to increase the temperature of the molten metal to improve the casting quality, it is necessary to take measures such as preventing the molten metal temperature from being set above a predetermined temperature to prevent combustion.

6. Summary

The experimental results in this study enable the determination of the conditions under which flame-retardant properties higher than those of SF_6 can be obtained. Hence, CF_3I was judged to be applicable in actual production facilities. The use of CF_3I is expected to reduce the greenhouse gases emitted by JATCO by 8%, thereby mitigating global warming. The use of CF_3I as a flame-retardant gas for Mg melting furnaces is the first such attempt in Japan, achieving compliance with PFAS regulations.

7. References

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