

4.3.5 ELECTRIC POWER SYSTEMS AND MAGNESIUM: SUBSTITUTES AND ALTERNATIVES FOR SF₆

Technology Description



Figure 1. Molten Mg with SF₆ cover gas.



Figure 2. Molten Mg without protective cover gas.

Electric Power Systems: Sulfur hexafluoride (SF₆) is a favored insulating agent for high-voltage electric power system equipment because of its dielectric strength and arc-suppression capabilities. Use of other insulating media has been researched and some have been used, especially in medium- and low-voltage applications. Historically, several other media were used (e.g., air, vacuum, oil) before the advent of SF₆, some of which remain in use today in certain applications. Emissions reductions can be achieved through the adoption of currently available “SF₆-Free” technologies (up to 145 kV) as well as through research into alternative gases and on-site recovery systems for such alternative gases and/or mixtures.

Magnesium Industry: Magnesium metal producers and casters use SF₆ mixed with dry air and/or CO₂ as a cover gas to prevent oxidation and burning of the molten metal. About 5% to 20% of the SF₆ is believed to react with the metal surface, preventing oxidation, while the remainder escapes to the atmosphere. The magnesium casting machine operators need to have access to the surface of the magnesium melt. Therefore, a tightly sealed system is difficult to engineer and maintain. Recognizing that some gas will escape, a highly attractive technology option involves use of a gas other than SF₆ with better environmental characteristics. The challenge is to isolate a substitute with low or no global-warming potential that satisfies the magnesium industry’s melt protection performance and safety requirements.

System Concepts

- Electric power systems: Purchase/use equipment that relies on insulating agents other than SF₆; Research, design, and development of “SF₆-Free” high-voltage equipment for the U.S. market.
- Magnesium casting: Use a gas for magnesium melt protection that avoids the global-warming concerns associated with SF₆.

Representative Technologies

- Electric power systems:
 - Existing insulating agents other than SF₆ include oil, air, or vacuum insulation; but SF₆ is the predominant choice for high-voltage applications. Despite extensive research efforts, no single gaseous compound has been isolated that serves as a substitute for SF₆ in high-voltage applications. SF₆ remains the insulating medium of choice. Gas mixtures, however, have been used successfully, including mixtures of SF₆/N₂ or SF₆/CF₄ in cold-weather applications.
 - 145kV vacuum interrupter (developed by Japan AE Power)

- **Magnesium casting:**
 - **HFC-134a:** The Cooperative Research Centre for Cast Metals Manufacturing (CAST) in Australia is conducting research and development to find a suitable substitute gas for SF₆. Based on the concept that the addition of fluorine into the magnesium oxide surface film is the key mechanism for preventing oxidation of molten magnesium, CAST has developed a process that uses the hydrofluorocarbon gas 1,1,1,2-tetrafluoroethane, otherwise known as HFC-134a.
 - **SO₂:** Sulfur dioxide provides effective protection of molten magnesium, but its toxicity presents a concern for use in the workplace.
 - **IMA Study / SINTEF:** The International Magnesium Association (IMA) established an Ad Hoc Committee on SF₆ composed of representatives from IMA, several magnesium casting firms, and an automobile manufacturer. The committee selected a research proposal from SINTEF, the Foundation of Scientific and Industrial Research at the Norwegian University of Science and Technology, to evaluate alternative cover gases for protection of molten magnesium.
 - **Novec 612™:** 3M™ has commercialized a fluorinated ketone, C₃F₇C(O)C₂F₅ (Novec 612™) as a substitute for SF₆.
 - **CO₂ “Snow”:** German researchers are investigating the efficacy of applying solid CO₂ “snow” to protect molten magnesium from oxidation. The CO₂ snow is reported to cool the melt surface and displace ambient air as it expands, thus limiting oxidation.

Technology Status/Application

- **Electric power systems:**
 - At least one utility is known to use SF₆/N₂ and SF₆/CF₄ gas mixtures for circuit breakers used in cold weather, at transmission and sub-transmission voltage levels (i.e., 500 kV and below);
 - EPRI is testing a “Solid State Current Limiter” - a “SF₆-Free” circuit breaker type device.
- **Magnesium casting:** HFC-134a and Novec 612™ are reported to provide good molten metal protection in magnesium production and die-casting applications. CO₂ snow protection is being studied at laboratory and pilot scales.

Current Research, Development, and Demonstration

RD&D Goals

- To find substitutes for SF₆ that have comparable insulating and arc quenching properties in high-voltage applications and/or protect molten magnesium – and significantly less or no global-warming potential.

RD&D Challenges

- **Electric power systems:** To date, no widely applicable alternatives have been found for SF₆. The primary RD&D challenge is to find an acceptable insulating medium for high-voltage applications; alternative gases will most likely require equipment modifications.
- **Magnesium casting:**
 - Characterizing chemical and physical mechanisms that govern protection of molten magnesium through use of cover gas.
 - Selecting effective gas substitutes that not only guard against magnesium burning, but also minimize emissions of greenhouse gases or other pollutants of concern.
 - Isolating the best methods of gas distribution to overcome the potential disturbances associated with magnesium melt turbulence and temperature.

RD&D Activities

- **Electric power systems:** The Electric Power Research Institute (EPRI) is investigating a solid-state current limiter that may lead to future equipment designs that do not require SF₆ insulation.
- **Magnesium casting:**
 - EPA and the magnesium industry are working in a voluntary partnership to eliminate SF₆ emissions
 - SINTEF and CAST continue their work with alternative gases and HFC-134a. Based on their findings regarding solubility of fluorine in molten magnesium, SINTEF is researching the viability of bubbling a fluorine-bearing gas through the melt or adding fluorine in a solid matrix, such as iron fluoride.

Recent Progress

- Electric power systems: Gas mixtures, as discussed above, have been used successfully in cold-weather applications; some equipment and gas manufacturers are devoting R&D resources into alternatives.
- Magnesium producers and casting firms report promising results from early production-scale trials of alternative fluorinated cover gases.

Commercialization and Deployment Activities

- 145kV vacuum interrupter commercially available in Japan.
- If a substitute gas is found, commercialization and deployment are not expected to represent hurdles. Gas mixtures appear to be readily available to potential users in cold regions where they are applicable.

Market Context

- Electric Power Systems: Circuit breaker equipment used in high-voltage electricity transmission and distribution; “SF₆-Free” power equipment, such as the 145kV vacuum breaker, is 2-3 times more expensive than high-voltage power equipment currently available in the market.
- Magnesium Industry: All magnesium production and casting firms that use SF₆ for magnesium melt protection.