COMBUSTION OF LITHIUM AND MAGNESIUM POWDERS FOR SPACE POWER APPLICATIONS.

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Introduction: There are many potential space missions where solar and nuclear energy cannot be used for power generation, and batteries cannot be used as a primary energy source either. In such cases, power could be generated by the so-called chemical heat integrated power systems using combustion reactions [1].

One such system involves combustion of lithium (Li) with sulfur hexafluoride (SF_6). An attractive feature of this system is that the products are condensed and their volume is less than that of the consumed Li. The Li-SF_6 combustion was successfully used to generate heat for the Rankine cycle in underwater propulsion systems [2]. For the power generation in Venus missions, Miller et al. [3] proposed to use in-situ CO_2 as the oxidizer. Their results show that Li, Mg, and an Mg/Al alloy, used with the in-situ CO_2, outperform the Li-SF_6 system and a sodium-sulfur battery. Among the three fuels, Li promises the highest electric energy per unit mass of the power system. Greer et al. [4] have constructed and tested Li-CO_2 batch reactors, but the results have shown a low combustion efficiency.

Recently, we have proposed an alternative approach based on the combustion of metal powders with O_2, supplied by a chemical oxygen generator [5]. In-situ CO_2 could be added to the O_2 flow. Specifically, we propose to fill a cylindrical reactor with a Li or Mg powder and to feed a gaseous oxidizer into it. The combustion wave propagation can be initiated by ignition at either the same end or the opposite one. The former leads to the coflow combustion, where the oxygen infiltrates through the products, while the latter leads to the counterflow regime, where the oxygen infiltrates through the initial powder.

The combustion of metal powders with infiltration of the reactive gas has been used for self-propagating high-temperature synthesis (SHS) of various metallic and nonmetallic nitrides and hydrides [6, 7]. The synthesis was usually conducted at pressures over 1000 bar in order to have a sufficient amount of the gaseous reactant in the pores. In the proposed combustors, the gas pressure will be much lower, which requires a rapid infiltration of oxygen through either the initial metal powder or the formed metal oxides. However, the infiltration-controlled combustion of metal powders is not well understood. Here we summarize our experimental results on the combustion of Li and Mg powders at natural infiltration of O_2 [8] and CO_2 [9].

Experimental: A magnesium powder (−325 mesh) and a stabilized lithium metal powder (SLMP®) were obtained from MilliporeSigma and Livent, respectively. Oxygen and carbon dioxide were obtained from Airgas.

The experiments were conducted in a laser ignition setup, which includes a windowed stainless-steel chamber, connected to a vacuum pump and a compressed gas cylinder. The ignition system includes a CO_2 laser, an infrared beam of which enters the chamber vertically through a zinc selenide window in the lid.

Quartz tubes were used to hold the metal powder during the experiment. The tube was installed vertically in a stainless-steel holder, several alumina tubes were installed vertically at the bottom of the quartz tube, and a thin layer of thermal insulation paper was placed on top of the alumina tubes to support the metal powder. The gas could penetrate into the powder from both ends.

The infrared beam of the CO_2 laser was aligned with the center of the top end of the sample using a red beam of a laser diode pointer, pre-aligned with the infrared beam. High-speed and infrared video recordings as well as thermocouple measurements were used for diagnostics.

Results: The experiments on combustion of Mg with O_2 were conducted at absolute pressures of 44-90 kPa. After burnout of the top layer, a thermal wave propagated downward, leading to ignition at the bottom and propagation of a second wave upward (Fig. 1). The second wave propagated at incomplete conversion in the coflow combustion regime, with the zone of the highest temperature traveling along a helical path.

The combustion characteristics were sensitive to the availability of the infiltrated oxygen. An increase in the axial velocity of the combustion wave was accompanied by an increase in the flame thickness and a decrease in the extent of conversion.

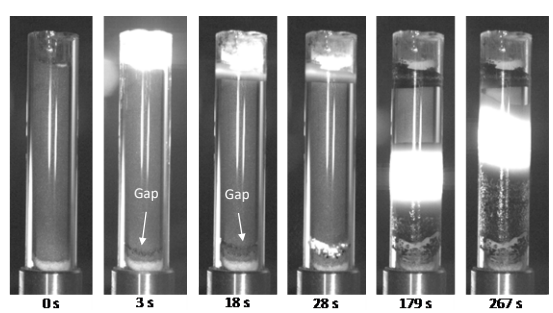

Fig. 1. Combustion of Mg powder (sample diameter: 7 mm) in oxygen at 90 kPa. Time is relative to the laser pulse. [8].

The experiments on combustion of Li with O_2 were conducted at pressures 13–90 kPa. At sample diameters 4–7 mm and 90 kPa, a self-sustained propagation of the combustion wave was observed (Fig. 2). After burnout of the top layer, a bright combustion wave propagates downward. After the combustion wave has reached the end of the sample, it continues to emit light for a significant time. Next, the brightness decreases from both ends, and eventually all the sample becomes dark.

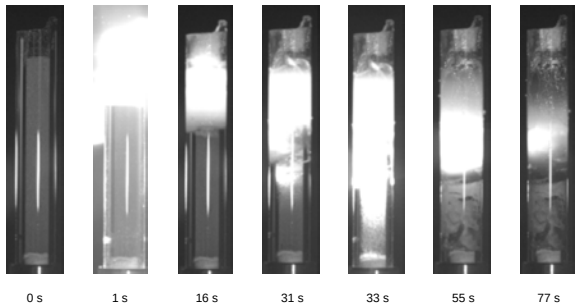

Fig. 2. Combustion of Li powder (sample diameter: 4 mm) in oxygen at 90 kPa. Time is relative to the laser pulse. [9].

Additional experiments have shown that the combustion wave propagates downward because oxygen infiltrates from the bottom, i.e., the counterflow combustion takes place. In some experiments, a second (coflow) wave propagated upward, but the first wave was still dominant.

In the experiments on combustion of Mg and Li powders in CO_2, a self-sustained propagation of the combustion wave was not achieved. The reaction was observed only in the top layer of the sample. Apparently, the produced carbon and CO prevent the infiltration of CO_2, making combustion in the used tubes impossible.

In a search for better conditions for combustion in a CO_2 environment, an experiment was conducted where 1 g of the Mg powder was placed as a 1 mm thick layer onto a ceramic paper inside the chamber, which was then filled with CO_2 at 90 kPa. The laser pulse ignited the powder, which then completely burned out.

Conclusions: Combustion of Mg and Li powders in quartz tubes at natural infiltration of a gaseous oxidizer has been studied. In O_2, a self-sustained combustion of both powders was observed. The first stage of this process was counterflow propagation of the combustion wave. In the case of Mg, this was followed by coflow propagation of the combustion wave in the opposite direction. In the case of Li, either the entire sample continued to react or the colflow combustion wave propagated as in the case of Mg. In CO_2, neither Mg nor Li exhibited a self-sustained combustion in the tubes, apparently because formation of carbon and CO prevented the infiltration of CO_2. In contrast, a layer of the Mg powder, ignited in CO_2, burned out completely.

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References: [1] Hendricks T. J. et al. (2020) *Conf. Advanced Power Systems for Deep Space Exploration.* [2] Hughes T. G. et al. (1983) *J. Energy, 7*, 128-133. [3] Miller T. F. et al. (2016) *Acta Astronaut., 127*, 197-208. [4] Greer, C. J. et al. (2021) *Acta Astronaut.*, 181, 235-248. [5] Shafirovich, E. et al. (2020) *Conf. Advanced Power Systems for Deep Space Exploration.* [6] Merzhanov A. G. (2008). *Int. J. Self-Propag. High-Temp. Synth., 17*, 242-265. [7] Varma A. et al. (1998) *Adv. Chem. Eng., 24*, 79-226. [8] Cordova S. et al. (2022) *Combust. Flame, 238*, 111950. [9] Estala-Rodriguez K. et al. (2022) *Proc. Combust. Inst.*, in review.