Utilization of waste aluminum for hydrogen production and material recycling

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Waste management and energy production are crucial fields for ensuring global sustainability. The increasing demand for aluminium in Europe, estimated to rise by 40 percent by 2050, underscores the need for effective waste management and the transition towards a circular economy [1]. Although recycling efforts have been made, a considerable quantity of aluminium waste still ends up in landfills, causing environmental pollution. Therefore, there is a pressing need to develop novel approaches to reduce the landfilling and waste of aluminium. This study aims to explore innovative scientific and engineering activities to harness the potential of waste aluminium for electricity generation through hydrogen production using the reaction between waste aluminium and water. The by-product obtained from this reaction can be further recycled back to aluminium through carbon-free electrolysis or utilized as a precursor to produce valuable materials.

This study proposes a novel concept (Figure 1): the utilization of low-value aluminium waste, such as powder, scraps, foil, wire, and product packages, for on-demand hydrogen production through reactions with water. These reactions yield 0.11 kg of hydrogen and approximately 4.3 kWh of heat per kilogram of aluminum [2]. The by-product of the reaction, mainly aluminium hydroxide ($Al(OH)_3$), can be recycled through an innovative carbon-free electrolysis process or serve as a precursor for the production of ceramics, enhancing overall efficiency and economic viability. This closed-loop approach offers the opportunity to generate electricity, heat, and valuable materials from otherwise underutilized waste aluminium. Hydrogen, as an energy carrier, offers an opportunity to replace fossil fuels and reduce atmospheric pollution. The proposed hydrogen production method using waste aluminium addresses the challenges associated with hydrogen storage by enabling real-time, on-demand hydrogen production and utilization.

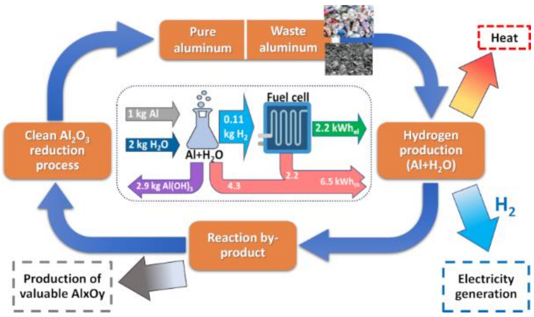

Figure 1. Recycling of waste aluminum and energy generation.

The formation of a thin protective oxide layer on aluminium's surface inhibits its reaction with water. Various strategies, such as the addition of hydroxide promoters (e.g., NaOH or KOH), aluminium oxide (Al_2O_3), salt promoters (e.g., NaCl or KCl), or activation by alloying, can disrupt the oxide layer and enable the aluminium-water reaction [3]. Notably, NaOH has been commonly used as the efficient promoter.

Several factors can influence the kinetics of the aluminium-water reaction: temperature, alkali concentration, water amount, aluminium mass, the ratio of aluminium to alkali concentration, and the heat dissipated during the reaction. The study's results indicate that temperature, in particular, plays a significant role in the reaction kinetics. Proper thermal insulation of the reaction vessel can even enhance the hydrogen production process by utilizing the heat generated in the exothermic reaction. Insulating the reaction vessel leads to self-promoted hydrogen production as the exothermic reaction produces heat inside the vessel. The activation energy for NaOH solution was calculated as 48.1 kJ/mol using the Arrhenius equation. Furthermore, the study investigates the reaction mechanism and analyzes the structure of the reaction's by-product at different stages. The analysis revealed that the by-product obtained from the alkali solution and dried under ambient conditions contains a substantial amount of thermonatrite, which results in a relatively low surface area (1-2 m^2/g). Therefore, to prevent contamination and enhance the surface area to over 200 m^2/g, an additional step of rinsing the by-product with distilled water is necessary.

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