An Economically Viable Process to Recover High-Value Products from Red Mud

Aluminum (Al) possesses many desirable properties: a high strength-to-weight ratio, corrosion resistance, thermal conductivity, and ductility. Over the past five decades, Al and its alloys have been used extensively for automotive, construction, electrical, and chemical applications. The growing demand for Al is met with an increase in demand for bauxite, a native ore for primary Al production.

Alumina (Al_2O_3) is leached from bauxite ore using the Bayer process, which also generates a residue called red mud. Red mud is a complex mineralogical mixture of primarily iron, aluminum, and titanium oxides in addition to some high-value rare-earth elements. For every ton of aluminum produced from bauxite, nearly 2.5–4 tons of red mud is produced. Since the advent of the Bayer process in the late 1800s, over 3 billion tons of red mud have been accumulated and stored in red mud ponds. The production of red mud, which recently reached 130 million tons per year, is expected to grow annually by about 6%.

The caustic nature and fine particle size of red mud makes the residue hazardous and expensive to contain. Despite attempts to reuse red mud and its constituents, so far commercial utilization of red mud has not been viable due to techno-economic challenges as well as lack of regulations.

▲ Researchers have developed a process for recovering metals with over 80% reduction in red mud waste — a hazardous byproduct of aluminum production that must be stored in holding ponds, such as this one.

Worcester Polytechnic Institute (WPI) researchers affiliated with the Center for Resource Recovery and Recycling (CR^3), an Industry-University Cooperative Research Center funded by the National Science Foundation (NSF), have developed a metallurgical process to extract iron oxide and rare-earth elements from red mud. The proprietary process can use red mud slurries directly from the Bayer process.

First, the slurries enter a hydrometallurgical leaching process to selectively extract iron, aluminum, and titanium. Then, a solid-liquid precipitation mechanism is used to selectively precipitate iron. Finally, the precipitated residue is converted into magnetite nanoparticles. Magnetite nanoparticles are extensively used in magnetically assisted drug delivery agents, pigments, fertilizers, and magnetic drives. In addition, the process offers a way to extract aluminum, titanium, and rare-earth elements (primarily scandium [Sc] and yttrium [Y]), which creates further value.

The new process overcomes many technical challenges, is more environmentally sustainable than storing red mud in ponds, and can be set up on-site at refineries, which reduces transportation costs. And, it can use slurries directly from the Bayer process, which reduces the operational costs incurred in drying the red mud (27% loss on ignition) that is required in competing pyrometallurgical strategies. Pyrometallurgical processes use carbon or CO gas at high temperatures to produce magnetite with much lower purity due to lack of selectivity. Costs can be further reduced by repurposing the new process's reagents via acid recovery.

Using the new metallurgical process, a plant processing 100,000 tons of red mud annually will produce 31,000 tons of magnetite nanoparticles at 99.9% purity. The new process can produce magnetite nanoparticles at a low temperature of around 70°C, which offers a competitive advantage over current high-temperature pyroprocesses that require temperatures above 600°C.

Competing processes have higher operational costs than the new process because they require a pure-grade precursor material, such as iron dichloride or iron(II) sulfate, to produce magnetite nanoparticles. In fact, after an economic analysis, the researchers found the new process had operational costs that were 46% lower than those of a competing process to produce magnetite nanoparticles and capital costs that were 52% lower. These economic projections are expected to improve dramatically if the extraction of other liberated elements, such as Sc, Y, Al, and Ti, is taken into account. This new metallurgical process is a promising, environmentally sustainable, and profitable means to close the loop in primary aluminum production.

In 2017, one of CR^3's industrial members, Global Mineral Recovery, Inc. (GMR), in partnership with Rio Tinto, launched a large-scale commercial venture to deliver a complete reclamation of bauxite residue into useful minerals, metallic oxides, and Earth-friendly materials. "This seminal research in CR^3 will be pivotal to the success of GMR," says GMR president Paul S. Kennedy. The joint venture will use technologies developed by the CR^3 researchers at WPI to separate red mud into its components and to completely recycle and commercialize the resulting products. CEP

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