Conceptual flowsheets for combined recovery of Fe and Al from bauxite residue

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Extended Abstract

Aluminium rise of demand within the global scale has introduced a major challenge towards mining industries in the handling of its by-product, bauxite residue (BR, red mud) with about 150 million tonnes of BR annually produced.[1] Bayer process is a caustic hydrometallurgical process that targets aluminium-bearing minerals from either lateritic or karstic ores. During digestion process and desilication steps, some aluminium (Al) and sodium (Na) remain lost by the formation of desilication products (DSP). BR also contains a significant portion of iron (Fe), calcium (Ca), silica (Si) and titanium (Ti) and about 0.1 wt% of critical metals such as scandium (Sc) and other rare earth elements (REEs). The active developments of technologies[2] often focus on multiple component recoveries, targeting Fe and Al as the major components in BR. This is followed by Ti, Sc and other REEs since treated residue is now enriched, allowing for more targeted approach towards critical metals recovery. This extended abstract proposes the conceptual flowsheets available for the pyrometallurgical recovery of the major metals, particularly Fe and Al.

Al extraction has been investigated using the soda sintering process[3-8], occurring between 800 to 1100 ^{o}C with the addition of soda and lime (if necessary). Al minerals are converted into leachable sodium aluminate form ($NaAlO_2$). Whereas, Fe can be recovered via two different carbothermic reductive process, which are either smelting or roasting with the addition of a carbon source and necessary fluxes. Smelting involves much higher temperatures to obtain molten slag and pig iron, whereas the latter reduces hematite into magnetic phases of Fe through the pathway of $Fe_2O_3 > Fe_3O_4 > FeO > Fe$.[2,9-11] Electric Arc Furnaces were most commonly used in scale-up smelting of BR, for Fe recovery and to condition the slag further for extraction of other components,[3-8,11-14] building material (clinkers or geopolymer[15]) or mineral wool.[16] The conditioned slag after smelting for Fe removal can further recover Al by forming leachable calcium aluminates or processed for Ti recovery via the carbo-chlorination route[13]. In reductive roasting environment, tube furnaces[11] which then scales up to rotary kilns[9], are used.

Figure 1 shows various pathways in approaching Fe and Al removal and Table 1 discusses the advantages and disadvantages of flowsheets.

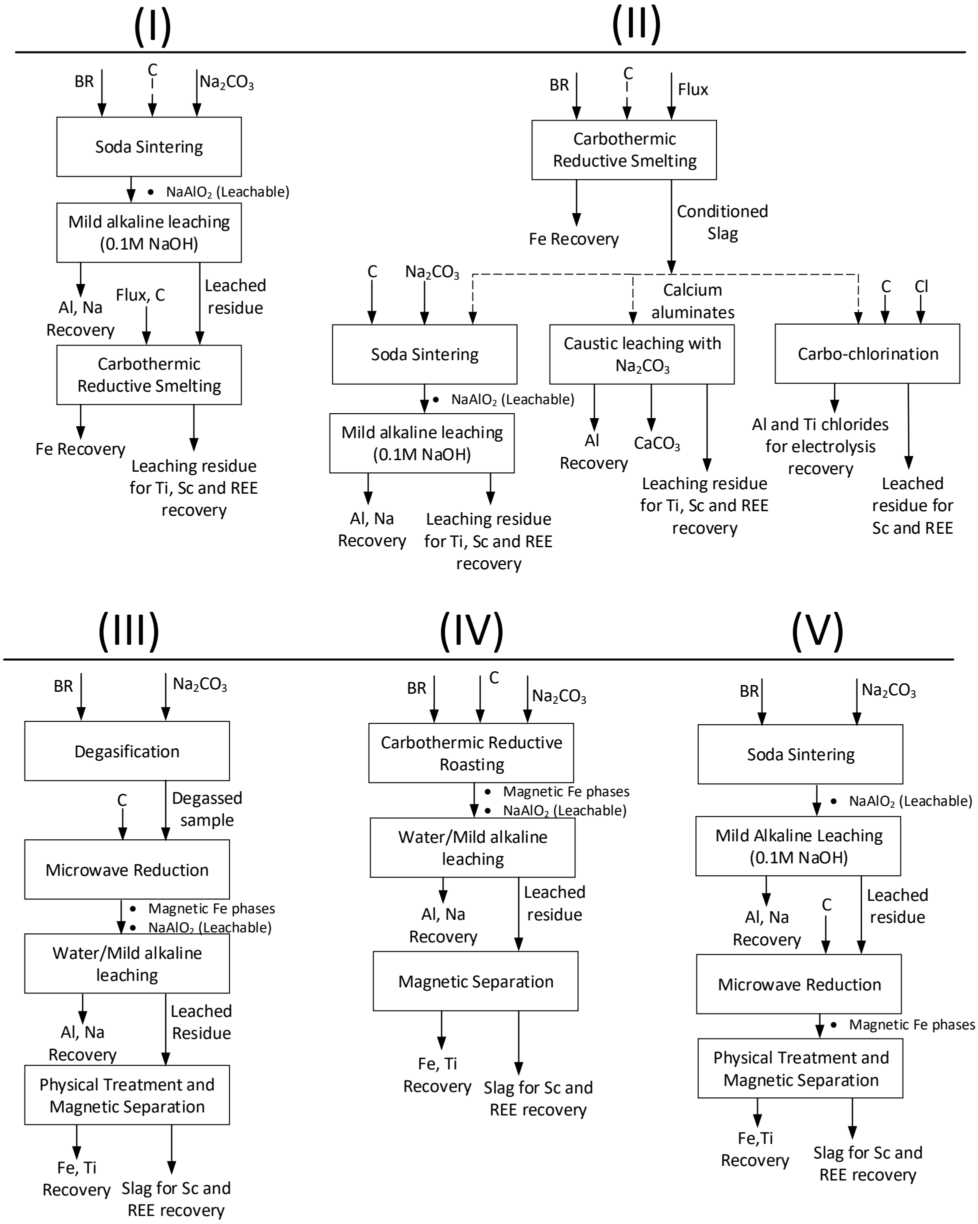

Figure 1. Conceptual flowsheets for combined recovery of Fe and Al from BR

Paths (I) and (II) explores different combinations of carbothermic reductive smelting and Al recovery processes (i.e. soda sintering, caustic leaching of calcium aluminates, or carbo-chlorination). Microwave reduction is specially noted as Path (III) due to inherent variability of electromagnetic energy that induces reductive process targeting the dielectric phases which is often completed in a fraction of time compared to traditional smelting or roasting furnaces.[2,10]

Table 1. Benchmark assessment, advantages and disadvantages of different processes

Path	Description	Advantages	Disadvantages
(I)	**Soda sintering followed by carbothermic smelting[3-8]**	+ Two-step process of recovering firstly Al and Na, followed by Fe + High throughput for the smelter + Reducing Na gaseous losses in smelting + Enriched and conditioned slag for downstream processing[7-8]	- Time, cost and energy intensive with introduction of leaching step before smelting
(II)	**Carbothermic smelting followed by soda sintering**	+ Enriched slag downstream allowing higher recoveries of Al, Ti, REEs downstream[18] + Mild fluxing conditions optimising Fe removal and preparing for Al and Na recovery	- Na losses in smelting increases soda demand - Excess CaO can be detrimental to downstream processing - High energy consumption in smelting due to fluxing
	Carbothermic smelting followed by caustic leaching (combined)[12,14]	+ Single-step heat recovery process targeting Fe, Al and Na through conditioning of slag + Downstream residue can be used for building materials	- Proper conditioning of leachable calcium aluminates necessary - $CaCO_3$ and $CaTiO_3$ inhibit downstream recoveries
	Carbothermic smelting followed by carbo-chlorination[13]	+ Fe removal and enriched slag targeting Al and Ti chlorides + Possible high recovery of Al as $AlCl_3$ easier to introduce into electrolysis, avoiding calcination step	- Possible operational challenges in carbo-chlorination step - $AlCl_3$ less favoured in electrolysis; corrosion problems and high maintenance costs - $TiCl_4$ recovery beneficial at enriched concentrations[19]
(III)	**Microwave reduction process (combined)[10]**	+ Microwave heating selectively focuses on moderately absorptive (dielectrics) materials + Highly reduced time of reduction via microwave	- Cost and size of microwave equipment, limited maximum power - Magnetic separation of Fe fractions require several step processing
(IV)	**Carbothermic reductive roasting (combined)[6-7,9]**	+ Addition of stoichiometric C assist Al and Na recovery[6,7] + Upscaling is easier in industrial equipment for larger batches + Minimal fluxing with lime aids downstream processing	- Fe recovery from maghemite and magnetic phase is lesser compared to metallic Fe recovery via smelting - Longer time needed compared to microwave process
(V)	**Soda sintering followed by microwave reduction**	+ Previous removal of Al and Na assists the Fe metallisation + Short duration of microwave Fe recovery assists processing	- Sintering and leaching step before microwave reduction costs energy and water.

An alternative hydrometallurgical route in Path (I) is Serial Combined Bayer-Sintering Process[17] involving leaching lime-soda sintered BR into Bayer digestion conditions instead of mild alkaline leaching, allowing reintroduction of liquor into

Bayer cycle. Finally, Paths (IV) and (V) explores carbothermic reductive roasting pathway with soda sintering in different sequences. By combining the many methods for Fe and Al removal, selecting favourable flowsheet, and conditioning downstream residues depending on target component and method of recovery, BR valorisation can be effectively accomplished.

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