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Current state of fine mineral tailings treatment: A critical review on theory and practice

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ABSTRACT

The mining industry produces fluid fine mineral tailings on the order of millions of tonnes each year, with billions of tonnes already stored globally. This trend is expected to escalate as demand for mineral products continues to grow with increasingly lower grade ores being more commonly exploited by hydrometallurgy. Ubiquitous presence and enrichment of fine solids such as silt and clays in fluid fine mineral tailings prevent efficient solid–liquid separation and timely re-use of valuable process water. Long-term storage of such fluid waste materials not only incurs a huge operating cost, but also creates substantial environmental liabilities of tailings ponds for mining operators. This review broadly examines current theoretical understandings and prevalent industrial practices on treating fine mineral tailings for greater water recovery and reduced environmental footprint of mining operations.

Contents

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1. Introduction

1.1. Fluid fine mineral tailings

Fluid fine mineral tailings refer to a mixture of waste by-products generated when recovering useful and precious minerals, metals, and other resources from the ores using mineral processing and hydrometallurgical processes. After selective extraction and beneficiation of the desired materials, the mill rejects and residuals are combined to form the tailings stream. In most cases the tailings are discharged in the form of a slurry into lagoons, engineered ponds and mine sites, where solids and process fluids separate under gravity. Given sufficient time, the nearly solids-free supernatant can be recycled into the extraction process to reduce freshwater intake and minimize waste volume. In very few instances the waste tailings has been discharged directly into the environment, although this practice is heavily declining and the practice is banned in many countries under more strict guidelines of zero discharge (Power et al., 2011; Samal et al., 2013). Discharge to tailings ponds remains an inexpensive and proven technology that has been widely adopted by the mineral industry (Watson et al., 2010). However, this approach often does not provide a long term tailings management solution.

With the ever-growing demand for mineral products, coupled with deterioration and depletion of high-grade mineral ore deposits, mining of lower-grade ores that are more resource- and energy-intensive to process is becoming the norm (Crowson, 2012; Bethell, 2012; Nesbitt, 2007; Jones and Boger, 2012). In these cases, sub-micrometer ore grinding and classification become inevitable to achieve the necessary mineral liberation and hence recovery using conventional mineral processing and hydrometallurgical processes. Unfortunately, fine grinding has also led to the reduced selectivity by the production of undesired fine gangue mineral solids. These fine solids, often only a few microns in diameter, are extremely difficult to separate from the tailings water. As a result they contribute directly to the accumulation of an alarmingly large volume of fluid waste mineral tailings that requires safe containment.

For example, typical coal preparation plants discharge 75–120 kg of dry tailings per tonne of coal processed. These tailings are in the slurry form, with total solid contents ranging between 20% and 35% (w/w) (Ryu et al., 2008; Beier and Sego, 2009; Murphy et al., 2012). In 2002, the U.S. National Research Council estimated that 70–90 million tonnes of tailings were produced annually by these facilities in the United States alone (National Research Council, 2002). Global inventory of the highly alkaline by-product (red mud) from alumina production using the Bayer process has surpassed 2.5 billion tonnes in 2007 with a predicted growth of 120 million tonnes per year, at an estimated ratio of 1–1.5 tonnes of red mud per tonne of alumina product, or 4 tonnes per tonne of finished aluminum (Kumar et al., 2006; Power et al., 2011). Production of phosphoric acid, an essential ingredient for the fertilizer ammonium phosphate, generates on average 450% of its weight as phosphogypsum (phosphate tailings) (Zhang and Stana, 2012). Given a worldwide phosphoric acid production of 40 million tonnes in 2010, about 180 million tonnes of acidic phosphate tailings require proper disposal (International Fertilizer Industry Association, 2010). At the extreme, extraction of copper generates a vastly disproportional amount of tailings. According to studies by Gordon and Bridge, 128–196 tonnes of combined copper tailings would be generated to produce 1 tonne of copper (Gordon, 2002; Bridge, 2000). Using Gordon's data, Onuaguluchi and Eren estimated a worldwide production of 2 billion tonnes of copper tailings in 2011 (Onuaguluchi and Eren, 2012).

A notable example outside mineral processing is found in northern Alberta (Canada) where bitumen production by surface mining has been a thriving industry for over 50 years. Located north of Fort McMurray, tailings slurry impoundment has created substantial land disturbances, covering an area of at least 130 km^2 in 2011 (Masliyah and Czarnecki, 2011). To produce one barrel of crude bitumen, 3.3 m^3 of tailings is discharged, containing 1.5 m^3 of fluid fine tailings (FFT) or mature fine tailings (MFT) that accumulate in the tailings pond after supernatant recovery (Masliyah and Czarnecki, 2011). These fluid fine tailings are stable at $\sim$30% (w/w) solids content without further noticeable densification for centuries. If one assumes that the density of the crude bitumen is approximately the same as that of water, then approximately 11.6 tonnes of MFT would be generated per tonne of crude bitumen produced. Recently, the Alberta Energy Regulator (formerly Energy Resources Conservation Board, ERCB) published the latest crude bitumen production figure of 340 million barrels from surface mining activities in 2012 (Alberta Energy Regulator, 2013). That amounts to an increase of approximately 510 million cubic meters (627.3 million tonnes) of fluid fine tailings.

1.2. Accumulated tailings issues

The huge volumes of mineral tailings are conventionally discharged into natural or engineered depressions, surrounded by dams and dykes that are critical to the structural integrity of the containment pond. Unfortunately, over the years there have been several incidents of dam failures and the disastrous release of tailings, which are often a result of extreme weather and/or natural disasters (WISE Uranium Project, 2012). The dam failures are a result of both geotechnical problems of the containment structure and management of the stored tailings (Jones and Boger, 2012). Several failures of fine coal tailings ponds in the United States have been documented by the U.S. National Research Council. One such disaster in West Virginia resulted in 125 fatalities and substantial environmental and property damage (National Research Council, 2002). In Ajka, Hungary, the unprecedented release of $\sim$700,000 m^3 of red mud slurry in October 2010 caused numerous fatalities as well as widespread farmland and waterborne contamination (Ruyters et al., 2011). Between 1967 and 2005, eleven