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Understanding oscillatory behaviour of gibbsite precipitation circuits

*Andrey V. Bekker, Tian S. Li, Iztok Livk**

CSIRO Mineral Resources Flagship, PO Box 7229, Karawara, WA 6152, Australia

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ABSTRACT

Gibbsite precipitation plays a central role in the production of alumina, the feedstock for aluminium smelters. A mathematical model of a simplified precipitation circuit is used in this work to investigate the main process parameters affecting the operating stability of gibbsite precipitation circuits incorporating solids classification and seed recycle. The crystallization process in continuous precipitation tanks is modelled using a dynamic crystallization population balance equation incorporating crystal growth, nucleation, and agglomeration kinetics. The precipitation circuit model provides a detailed particle size distribution response, which is crucial for evaluating the circuit's precipitation yield and product properties. Transient responses of the precipitation circuit model were investigated for key process parameters. It is shown that a rectangular pulse disturbance in the feed flow rate can generate an oscillatory response of the precipitation circuit if the solids residence time in the classification section is comparable in magnitude to the total slurry residence time in the precipitation section. An oscillatory circuit response has a detrimental effect on the product particle size distribution, but only slightly affects the production rate. Oscillations in the product mean size are believed to be a result of the impact of the main precipitation process variables on the gibbsite agglomeration rate.

1. Introduction

Gibbsite precipitation plays a central role in the production of alumina, the feedstock for aluminium smelters. The total world alumina production is higher than 100 Mt, with around 6% compound annual growth in the last decade (Alumina Production Global Data for Jan 1974 to Jun 2014, 2014). To ascertain high precipitation yield and product quality in the Bayer process alumina refineries, a significant amount of crystals in gibbsite precipitation circuits is continuously recycled, which is achieved through the classification of particulate solids coming out of the last precipitation tank. This leads to potentially complex recycling strategies, long total solids residence times, and accumulation of disturbances, which result in a process that is difficult to operate in a stable manner. Examples of different Bayer precipitation circuit configurations are provided by Stephenson and Kapraun (2013), Cruz et al. (2013), and Franco and Junior (2014). Oscillatory behaviour in crystallisers has been investigated previously by Randolph and Larson (1988). They clearly demonstrated by simulation that independently of an external disturbance a single crystalliser with a fines-dissolution loop can exhibit sustained oscillations in crystal mean-size and solids concentration. Furthermore, Eek (1995) showed, experimentally and numerically, the existence of sustained oscillations in an evaporative crystalliser with a fines-removal feedback loop. More recently, Du and Ydstie (2013) derived global stability conditions for a single continuous crystallizer taking into account nucleation and crystal growth kinetics. Closed loop dynamics of a continuous protein crystallizer, equipped with a fines trap and a product classification unit, were studied by Kwon et al. (2014).

* *Corresponding author*. Tel.: +61 8 93348902.
E-mail address: iztok.livk@csiro.au (I. Livk).

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Nomenclature

B	birth function for crystal aggregation ($m^{-4}\,s^{-1}$)
B_0	secondary nucleation rate ($m^{-3}\,s^{-1}$)
D	death function for crystal aggregation ($m^{-4}\,s^{-1}$)
F	slurry flow rate ($m^3\,s^{-1}$)
G	linear crystal growth rate ($m\,s^{-1}$)
k_V	volume shape factor
L	crystal size (m)
L_0	smallest crystal size (m)
n	number density (m^{-4})
S	classification function
t	time (s)
V	precipitator volume (m^3)

Greek letters

α	conversion factor from $Al(OH)_3$ to Al_2O_3
ε	ratio of liquid volume to total slurry volume
μ_2	second moment of crystal size distribution ($m^2\,m^{-3}$)
ρ_s	density of solids ($kg\,m^{-3}$)
τ_s	residence time of solids in classification thickener
$\tau_{s,c}$	total residence time of solids in classification

Predicting a Bayer precipitation circuit response to changes in operating parameters is very challenging due to the nonlinear gibbsite crystallization kinetics and long precipitation circuit response times that can extend to several months. A mathematical model, built for a simplified precipitation circuit, is used in this work to investigate operating parameters affecting the operating stability of gibbsite precipitation circuits. The crystallization process in continuous precipitation tanks is simulated using a dynamic crystallization population balance equation (PBE) model incorporating crystal growth, secondary nucleation, and agglomeration kinetics. The PBE-based gibbsite crystallization model and its constituent crystallization kinetics equations have been described in more detail in previous publications (Bekker et al., 2011; Heath and Livk, 2006; Ilievski and Livk, 2006). A dynamic population balance based precipitation model used in the current work provides a powerful tool for studying response of such gibbsite precipitation circuits. The precipitation circuit model predicts a detailed particle size distribution response, which is crucial for evaluating the overall precipitation yield and product properties. Sensitivity and transient responses of the precipitation circuit model were investigated for key operational parameters. It is shown that a rectangular pulse change in the feed flow rate generates an oscillatory response of the precipitation circuit model if a solids time-delay is present in the circuit classification section. The potential of such oscillatory responses to adversely affect the precipitation circuit operation and product quality is assessed based on simulation results.

2. Oscillations in the gibbsite precipitation circuit

It is well known that due to nonlinear gibbsite precipitation kinetics and complex solids recycling layouts, Bayer precipitation circuits can exhibit operating instabilities (Audet et al., 2012). Oscillatory behaviour of the Bayer precipitation circuit has also been described in the work of Wu et al. (2010). The authors showed that the oscillation period can vary from several days to several months depending on the precipitation circuit total volume. In some previous work, the oscillatory behaviour of gibbsite precipitation circuits has been associated with the intermittent occurrence of impurities in the Bayer liquor such as oxalates (Power et al., 2011). In the work of Reyhani et al. (1999) sodium oxalate was also considered a source of circuit oscillatory behaviour. As discussed in their paper, when oxalate exceeds a critical concentration, it can crystallise as solid phase oxalate (SPO), which can further promote gibbsite secondary nucleation. This type of explanation of circuit oscillations, however, is not adequate for explaining oscillations in new precipitation circuits, where the oxalate concentration during the first few years of operation is typically much lower than the critical oxalate concentration. Current model simulations, therefore, were performed without taking into account the presence of SPO in a gibbsite precipitation circuit.

In this work, a solids time-delay in the classification unit is investigated as a source of the precipitation circuit oscillations. This type of oscillations does not require the presence of oxalate impurities in the circuit feed liquor. This solids time-delay is connected to the gravity thickeners used in the classification section of the precipitation circuit as shown in Figs. 1 and 2. Due to their very large volume, gravity thickeners can introduce very long solids residence times into the precipitation circuit. This behaviour is captured in the model by introducing a large solids time-delay in the classification

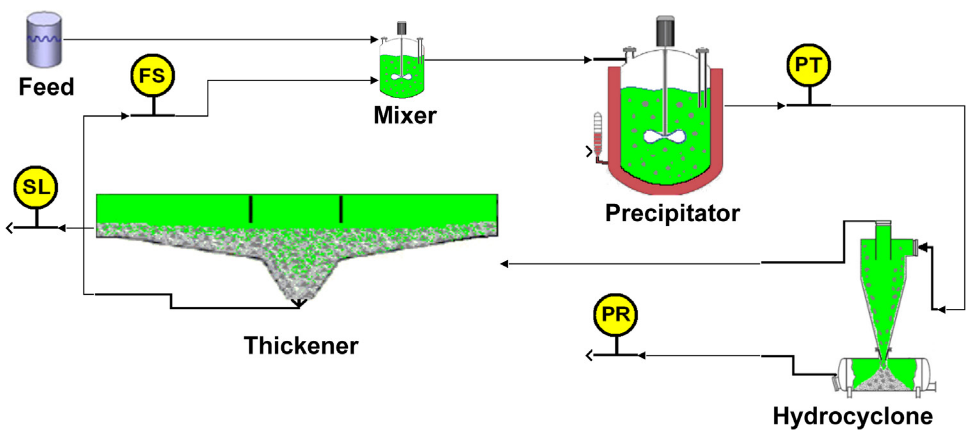

Fig. 1 – Schematics of a simplified precipitation circuit with a single precipitator, precipitation product classification, and a fine seed recycle.