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# Numerical simulation of flow regions in red mud separation thickener's feedwell by analysis of residence-time distribution

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**Abstract:** The residence-time distribution (RTD) and the compartment model were applied to characterizing the flow regions in red mud separation thickener's feedwells. Combined with the experimental work, validated mathematical model as well as three-dimensional computational fluid dynamics (CFD) model was established to analyze the flow regions of feedwells on an industrial scale. The concept of RTD, although a well-known method for the characterization of mixing behavior in conventional mixers and reactors, is still a novel measure for the characterization of mixing in feedwells. Numerical simulation results show that the inlet feed rate and the aspect ratio of feedwells are the most critical parameters which affect the RTD of feedwell. Further simulation experiments were then carried out. Under the optimal operation conditions, the volume fraction of dead zone can reduce by10.8% and an increasement of mixing flow volume fraction by 6.5% is also observed. There is an optimum feed inlet rate depending on the feedwell design. The CFD model in conjunction with the RTD analysis then can be used as an effective tool in the design, evaluation and optimization of thickener feedwell in the red mud separation.

**Key words:** computational fluid dynamics; residence-time distribution; compartment model; feedwell

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## 1 Introduction

Thickeners are key unit in the Bayer alumina refining processing operations and are used to separate insoluble solid, usually red mud from the liquid feed slurry under the action of gravity. Thickeners enable the treatment of vast volumes of dilute feed slurry that passes through a central feedwell, with the intention of dissipating the incoming stream kinetic energy and gently discharging stream into the tank [1]. A rake, usually mounted on central shaft, is installed at the bottom of the thickener. As a result, the solids would settle down to form the dense underflow while the clarified liquor is collected at the peripheral overflow. Synthetic flocculant is often added to enhance settling by creating large fast settling aggregates which will provide the potential for greater throughput and higher utilization efficiency of the thickener.

The flow in the thickener's feedwells is of critical importance to the performance of the thickener as a whole since it is here that most stream's kinetic energy dissipation, flocculant mixing and aggregation process occur [2]. As a result, a quantitative description for the process mentioned above is therefore required. Furthermore, the transportation of the insoluble solids from feed slurry to various points in the tank is also governed by the hydrodynamic and turbulent mixing within the feedwell. Unless the feedwell is properly designed, detrimental effects can occur and have negative influence on settling. However, the thickening process is poorly understood and predictive design of thickening devices is still primarily empirical. It was indicated that the previous studies in the area did not supply sufficient insights for practical thickener design and operational issues [3]. Presently, the availability of method for feedwell design is far inadequate to meet the demand.

Numerical simulations have already proved their potential in the investigation for thickening process. A

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number of publications have applied CFD to studying the hydrodynamics within thickeners as well as other industrial settling devices [4−7]; however, they merely focused on no-mineral applications and feedwells were not taken into consideration. PELOQUIN et al [8] applied conventional CFD to a bauxite residue thickener to show the flow patterns on the feedwell, and a optimization flow and solid concentration inside feedwell were gained by installing a baffle ring in the feedwell. WHITE et al [1] established a single-phase, three-dimensional CFD model to calculate the fluid flow in the feedwells, and the *k*-epsilon turbulence model was proven to be adequate enough to simulate the turbulent flow of the feedwell by experimental validation. The flocculation absorption mechanisms were combined into CFD calculation by KAHANE et al [2]. Modification on a plant feedwell was then carried out based on the CFD modeling and higher throughput was achieved [9]. TRIGLAVCANIN [10] modeled a number of design options for maintaining turbulence and mixing time in low aspect ratio feedwells, including alternative concepts from the manufactures. CFD investigation on feedwells has obviously been done by many institutes and thickener manufactures, but rarely published in any details due to confidential issues [11]. The flocculation process requires suitable mixing of the flocculant solutions with the incoming slurry. Such behaviors have rarely been studied and optimized since mixing conditions may not be an issue in many large, over-sized feedwells. However, the trend of high rate of red mud thickening as well as environmental and capital restriction requires higher demands on thickening performance in terms of throughput, over and under flow properties.

In this study, an investigation focused on mixing behaviors of the thickener's feedwell was performed using both numerical and experimental approaches. Numerical analysis was carried out by simulating the turbulent flow inside feedwells. The concept of RTD was applied to quantifying the mixing behavior for the thickener feedwells combining hydraulic model experiment validation based on the similarity theory. Then, a series of experiments were then carried out and the optimal operation condition based on the very design of the conventional feedwell was presented.

## 2 Residence-time distribution model and parameters of RTD curve

Residence-time [12], also known as removal time is the average time that a particle spends in a particular system. Unlike in ideal reactor system, the residence time of the fluid elements in the feedwells is not equal, which makes RTD be used for the characterization of the mixing conditions. The RTD is usually obtained by injecting a tracer instantaneously (a pulse input) or at a constant rate (a step input) at the inlet of the feedwells. The RTD function $E(t)$ can be then established by measuring the tracer concentration at the feedwell outlet as a function of time. $E(t)$ gives how much time different fluid elements have spent in the feedwell. Generally, the pulse input method is used since it can avoid the numerical errors in differentiation which is inherent in step input method. The RTD function is given in Eq. (1), where $C(t)$ is the tracer concentration at the feedwell outlet as a function of time.

$$E(t)=\frac{C(t)}{\int_0^{\infty}C(t)\mathrm{d}t} \tag{1}$$

When the RTD function is obtained, some parameters that can give quantitative description on the flow pattern can be calculated based on the compartment model [13−15].

Actual mean residence time can be written as follows:

$$t_{\mathrm{m}}=\frac{\int_0^{2\tau}tE(t)\mathrm{d}t}{\int_0^{2\tau}E(t)\mathrm{d}t} \tag{2}$$

Theoretical mean residence time can be written as follows:

$$\tau=\frac{V}{Q} \tag{3}$$

Dead volume fraction can be written as follows:

$$\frac{V_{\mathrm{d}}}{V}=1-\frac{t_{\mathrm{m}}}{\tau} \tag{4}$$

Dispersed plug volume fraction can be written as follows:

$$\frac{V_{\mathrm{p}}}{V}=\frac{t_{\max}}{\tau} \tag{5}$$

Mixed volume fraction can be written as follows:

$$\frac{V_{\mathrm{m}}}{V}=1-\frac{V_{\mathrm{d}}}{V}-\frac{V_{\mathrm{p}}}{V} \tag{6}$$

where $t_{\mathrm{m}}$ is the mean residence time which presents the average time of the fluids elements spend in the feedwell; $V$ and $Q$ represent the total volume fraction of the feedwell and incoming slurry volumetric flow rate, respectively; $t_{\max}$ is the time to obtain the maximum $E(t)$.

When investigating the flow mixing performance of the feedwells for different sizes or boundary conditions, a normalized RTD function $E(\theta)$ is incorporated by Eqs. (7) and (8), where $\theta$ is the dimensionless time.

$$E(\theta)=\tau E(t) \tag{7}$$

$$\theta=\frac{t}{\tau} \tag{8}$$