Assessment of flow pattern and mixing phenomena in alumina digesters

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Abstract

In Bayer process, alumina is extracted from bauxite by double digestion process followed by precipitation of green liquor and calcination of hydrate particles to produce metallurgical grade alumina. In general, industry scale high temperature digesters are equipped with a multi-stage agitator design. Apart from the agitator, digester internal design plays a vital role that determines the quality of flow and in turn, affects the extraction efficiency of bauxite digestion. Short circuiting (channelling), excess back mixing of slurry, and formation of dead zones are the common engineering challenges faced by taller aspect ratio digester designs. The current analysis is focused on investigation and assessment of the effect of digester internal design on the flow pattern and mixing phenomena using computational fluid dynamics (CFD) modeling and validated using flow visualization experiments.

Keywords: Bayer process digester; digester agitator design; CFD modelling of Bayer process digesters; Dispersion number; *E* curve.

1. Introduction

The Hindalco alumina refineries in India are based on the Bayer process technology. The refinery is basically classified into two major areas called redside and whiteside. The technology has to follow four important steps in the Bayer process for the production of alumina i.e., grinding and digestion, solid-liquid separation, precipitation and calcination. Digestion is the unit process that is vital in determining the productivity from the redside of the technology. The main raw material input for the digestion area of an alumina plant is the bauxite slurry coming from the pre-desilication, or slurry storage processes. The bauxite at the Muri refinery has boehmite content varying from 8 to 12 %, hence high temperature digesters are needed to recover boehmite content succeeding the gibbsite digestion. The primary chemical reaction in high temperature digestion is as follows

$$Al_2O_3.H_2O + 2\mathrm{NaOH} \xrightarrow{245^oC} 2\mathrm{Na}AlO_2 + 2H_2O \qquad \textbf{(1)}$$

During the high temperature dissolution process, the alumina from bauxite gets dissolved in the Bayer liquor in the form of sodium aluminate and the insoluble residue (red mud) will be separated from sodium aluminate in the subsequent clarification operation. In general, the effectiveness of the dissolution process strongly depends upon the reaction kinetics, hydrodynamics and physical operating conditions prevailing in the digestor. The reaction chemistry of the alumina extraction is a function of minerals association in the bauxite, grain phase size distribution and type of overall mineral chemistry composition. However, for the given bauxite quality, operating conditions and hydrodynamics in the digester can always be

altered to favor the maximum extraction efficiency with an economic recovery. One of the major focus for today's alumina refineries must be to improve the energy efficiency due to the current variation of specific energy consumption of global alumina refineries from 7 to 24 GJ/T. Further, the energy consumption is particularly design specific with respect to digestion and calcination which together account for more than seventy percentage of refinery thermal energy consumption. So it is imperative to look into the detailed design of the digester to obtain a maximum extraction efficiency. The effectiveness of the digester varies dramatically from one design to the other. The design variations could be with respect to the shape and size of the digester, inlet/outlet (location, orientation, and shape), internals design (baffles, impeller type, impeller shape and impeller size) and with respect to agitator speed [1, 2]. This implies that hydrodynamics plays a major role in an industry scale effective dissolution process for the given bauxite quality. In the past decade, CFD has become a vibrant tool to optimize the process designs in the hydrometallurgical industries; especially the alumina industries [3 – 5]. In the present work, an attempt has been made to assess and validate the flow and mixing pattern of bauxite slurry in the high temperature digesters.

2. CFD modeling and simulation

Even though CFD simulation is becoming increasingly popular among hydrometallurgical industries [3, 4, 6]; few literature references are available specific to alumina digester analysis. [4] successfully modelled the digester slurry hydrodynamics as a single phase to study the influence of vessel aspect ratio and inlet configuration for the selection of preferred vessel geometry. Also, [2] simulated the hydrodynamics of bauxite slurry in the low temperature digesters assuming a homogeneous and non-settling slurry. In the present analysis, similar physical properties have been considered for the bauxite slurry. Figure 1 shows three digesters.

The geometry and the tetrahedral meshing is done using ANSYS-ICEM 14 and numerical simulations are carried out using ANSYS-Fluent 14. The turbulence is modeled using a single phase realizable k-ε model. This model provides a superior performance for flows involving rotation, boundary layers under strong adverse pressure gradients, separation and recirculation against the standard k-ε turbulence model. The 3D computational tetrahedral elements are around 600 000 for the present digester design. The modeled transport equations for k and ε in the realizable k-ε model are as follows

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_j) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon - Y_M + S_k \quad \textbf{(2)}$$

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_j}(\rho\epsilon u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \epsilon}{\partial x_j}\right] + \rho C_1 S_\epsilon + \rho C_2 \frac{\epsilon^2}{k + \sqrt{\nu\epsilon}} + C_{1_\epsilon}\frac{\epsilon}{k}C_{3_\epsilon}G_b + S_\epsilon \quad \textbf{(3)}$$

where:

$$C_1 = max\left[0.43, \frac{\eta}{\eta+5}\right] \; and \; \eta = \frac{k}{\epsilon} \quad (3a)$$

In the case of the standard k-ε model, the eddy viscosity, μ_t has a constant C_μ value whereas the realizable k-ε model has C_μ, which is dependent upon the mean strain and rotation rates, the angular velocity of the impeller rotation and turbulence fields, k and ε. In the literature, it was found that the realizable k-ε model extensively validated for a wide range of flows i.e., rotating

S_ϵ Source term of energy dissipation (kg m^{-1} s^{-3})
S_k Source term of k (kg m^{-1} s^{-3})
σ Standard deviation of tracer (s)
t Time (s)
T Tank diameter (m)
t_m Mean residence time (s)
τ Agitator torque (Nm)
u Characteristic velocity (m s^{-1})
U_r Mean radial velocity (m s^{-1})
U_z Mean axial velocity (m s^{-1})
V Volume of digester (m^3)
Y_M Dilatation dissipation factor (kg m^{-1} s^{-3})
z Axial coordinate location (m)

9. Dimensionless groups

D/uL Dispersion number
E Exit age distribution function
E_P Primary pumping efficiency of an impeller
E_T Total pumping efficiency of an impeller
H/T Aspect ratio of digester
σ_t Coefficient of variance (σ/t_m)
σ_k Turbulent Prandtl number for k
N_P Impeller power number
$\langle N_P \rangle$ Agitator power number
N_{QP} Primary flow number
N_{QS} Secondary flow number
P/V Power per unit volume

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