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Industrial Scale Reactor Design for Al_2O_3 Production from Bauxite and Sodium Hydroxide Solution

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ABSTRACT

The aim of this study is to design a reactor that can optimize the production of Al_2O_3 from the reaction between bauxite and sodium hydroxide solution on an industrial scale. The type of reactor used for the production of Al_2O_3 nanoparticles is a Continuous Flow Stirred – Tank Reactor (CSTR). The method used in this study is to perform computational analysis and calculation of the dimensions of the reactor and stirrer as well as the mass balance, using basic calculation with Microsoft Excel application. To produce Al_2O_3 nanoparticles on an industrial scale, three reactor units and three stirrers are required. Based on the calculation results, it is found that the first and second reactors have volume 2,9689 m^3 with height 5,0424 ft and require a stirrer with six blades with an angle of 45^o which has power 50 Hp. The third reactor has volume 4,3387 m^3 with height 9,0847 ft and requires one stirrer with six blades with an angle of 45^o which has a power 75 Hp. The computational calculation results in this study can be used as an overview in designing a reactor to produce Al_2O_3 nanoparticles from bauxite and sodium hydroxide solution on an industrial scale.
Keywords : *Aluminium Oxide, Bauxite, Reactor Design, CSTR, Sodium Hidroxide*

ABSTRAK

Tujuan dari penelitian ini adalah merancang reaktor yang dapat mengoptimalkan produksi Al2O3 dari reaksi antara bauksit dan larutan natrium hidroksida dalam skala industri. Jenis reaktor yang digunakan untuk produksi nanopartikel Al_2O_3 adalah Continuous Flow Stirred – Tank Reactor (CSTR). Metode yang digunakan dalam penelitian ini adalah melakukan analisis komputasi dan perhitungan dimensi reaktor dan pengaduk serta neraca massa, menggunakan perhitungan dasar dengan aplikasi Microsoft Excel. Untuk menghasilkan nanopartikel Al_2O_3 dalam skala industri, diperlukan tiga unit reaktor dan tiga pengaduk. Berdasarkan hasil perhitungan diketahui bahwa reaktor pertama dan kedua memiliki volume 2,9689 m^3 dengan tinggi 5,0424 ft dan membutuhkan pengaduk dengan enam sudu dengan sudut 45^o yang memiliki daya 50 Hp. Reaktor ketiga memiliki volume 4,3387 m^3 dengan tinggi 9,0847 ft dan membutuhkan pengaduk dengan enam bilah dengan sudut 45^o yang memiliki daya 75 Hp. Hasil komputasi pada penelitian ini dapat digunakan sebagai gambaran dalam perancangan reaktor untuk menghasilkan nanopartikel Al_2O_3 dari larutan bauksit dan natrium hidroksida pada skala industri.
Kata Kunci: Aluminium Oksida, Bauksit, Desain Reaktor, CSTR, Natrium Hidroksida.

INTRODUCTION

Recently nano-sized alumina has attracted much attention due to its wide applications in different fields due to their larger surface area at their nano-scale range as compared to micron size and finds applications in nano-machining and nano-probes (Tok et al, 2006). High-quality ceramics can only be obtained using nano-size of transition alumina (Laine et al, 2006) that can be used for drug delivery applications (Granado et al, 1997) and for high-temperature applications, adsorbents, coatings and soft abrasives (Kim et al, 2007). It can either be used as a thin film in the microelectronic industry as dielectric layers, refractory, anticorrosive and antireflective coatings (Tadanaga, et al., 2008) wave-guide sensors (Yamaguchi et al, 2009), and buffer layers (Kim et al, 1997)or as nanoparticles in catalysis, structural materials and as membranes etc.

Much research has already been done for alumina nanoparticles obtained by numerous solution-based techniques such as sol-gel (Roy, 1987) (Bahlawane & Watanabe, 2000) (Nayar, et al., 2020), hydrothermal (Kaya et al, 2002), microwave (Deng & Lin, 1997) and microemulsions (Pang & Bao, 2002) but there are very few studies based on comparing the phase transformation behaviour of nanoparticles obtained from different techniques. Metastable phases of Al_2O_3 are unstable and transform to stable α-phase upon heat treatment either in-situ by keeping the combustion temperature high or ex-situ by postdeposition annealing.

Al_2O_3 nanoparticles have many uses, including in ceramics, catalysts, polymer modification, and heat transfer fluids (Nazari et al, 2010). Besides that, this nanoparticle has many advantages in biomedical applications, such as in drug delivery systems, anti-microbial and anti-bacteria, immunotherapy, and many more (Prakash, et al., 2018). Due to its wide use, the production of Al_2O_3 is required.

Reactor is needed to produce Al_2O_3 nanoparticles on an industrial scale. There are several types of reactors that can be used, one of which is the Continuous Flow Stirred – Tank Reactor (CSTR). For this study, our attention was focused on the continuous stirred tank reactor (CSTR) design for the production of Al_2O_3 nanoparticles from the reaction of bauxite with sodium hydroxide solution.

METHOD

1. Synthesis of Al_2O_3 nanoparticle

Synthesis of Al_2O_3 is carried out using the Bayer process, based on research procedures that have been carried out by Rahma & Yusuf, 2020. In the Bayer process the raw materials used are high grade bauxite with alumina content above 50%, Bauxite contains Al_2O_3 compounds (45-65%), SiO_2 (1-12%), Fe_2O_3 (2-25%), TiO_2 (> 3%) and the rest H_2O (14-36%) (Gow & Lozej, 1993).

The compound Al_2O_3 in bauxite forms a complex with water to form $Al_2O_3.H_2O$ (aluminum oxide monohydrade) and $Al_2O_3.3H_2O$ (aluminum oxide trihydrade) (Azof et al, 2020).

First, the bauxite is reacted with sodium hydroxide in a reactor or digestion where gibbsite Al_2O_3 will dissolve to form sodium aluminate ($NaAlO_2$). This reaction is carried out at a temperature of 140°C and a pressure of 4 - 4.5 atm. Reaction equation when digested:

$$Al_2O_3.3H_2O_{(s)} + 2NaOH_{(aq)} \rightarrow 2NaAlO_{2(aq)} + 4H_2O_{(l)}$$

Then $NaAlO_2$ is precipitated in the precipitator by absorbing water to form the compound $Al_2O_3.3H_2O$ at a temperature of 60°C, a pressure of 1 atm and a conversion of 90 – 95% Precipitation reaction equation:

$$2NaAlO_{2(aq)} + 4H_2O_{(l)} \rightarrow Al_2O_3.3H_2O_{(s)} + 2NaOH_{(aq)}$$

Trihydrate aluminum oxide ($Al_2O_3.3H_2O$) is then heated in the kiln at 1200°C, 1 atm pressure, conversion 99.9%. To release the hydrate compound to form aluminum oxide (Al_2O_3). Reaction equation in the kiln:

$$Al_2O_3.3H_2O_{(s)} \rightarrow Al_2O_{3(s)} + 3H_2O_{(g)}$$

(Aziz et al, 2009)

2. Mathematical design of reactor

The mathematical design and mass balance analysis is performed manually using the Microsoft Excel application when collecting data (equation 1-10). The reactor and stirrer parameters that were calculated is shown in Table 1.

Table 1. shows the reactor design parameter calculations. The construction material for the reactor design is stainless steel SA – 193 Grade B16. We assumed that the conversion is 99% and for the mixer that we used is axial turbin 6 blades angle 45°. Various types of calculations, such as determination of reactant volume, reactor design, and mixer design with some assupmtion are calculated manually using Microsoft Excel

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Table 1. Calculation of reactor and stirrer parameters

Section	Parameter	Equation	Eq
Reactor dimension	Reactor volume	$\text{volumetric rate} = \frac{\text{volume input}}{\rho \text{ total}}$	1
	Vessel diameter	$\text{total volume} = \frac{\pi \text{ x di}^3}{24 \tan\frac{1}{2}\alpha} + \frac{\pi \text{ x di}^2}{4} \text{ x Ls x } 0{,}0847 \text{ di}^3$ Where π = 3,14 di = vessel diameter Ls = 1,5 di	2
	Liquid volume in cylinder	$Vls = Volume\ liquid - Top\ cover\ volume$ Where Vls = liquid volume in cylinder	3
	Liquid height in cylinder	$Lls = \frac{Vls}{(\frac{\pi}{4}) \times di^2}$ Where Lls = liquid height in cylinder Vls = liquid volume in cylinder di = vessel diameter	4
	Design pressure	$P_i = P_{atm} + P_{hidrostatik}$	5
	Cylinder thickness	$ts = \frac{Pi \times di}{2(f \times E - 0{,}6Pi)} + C$ Where ts = cylinder thickness f = allowable stress E = efficiency P = pressure C = corrosion allowance	6
	Height cylinder	$total\ volume = \frac{\pi \times di^3}{24 \tan\frac{1}{2}\alpha} + \frac{\pi \times di^2}{4} \times Ls \times 0{,}0847 di^3$ Where π = 3,14 di = vessel diameter Ls = 1,5 di	7

Cover dimension	Top cover	$$ha = \frac{0{,}885 \times Pi \times di}{2(f \times E - 0{,}1Pi)} + C$$ Where ha = top cover thickness f = allowable stress E = efficiency P = pressure C = corrosion allowance	8
	Bottom cover	$$ha = \frac{Pi \times di}{2(f \times E - 0{,}6Pi)\cos\frac{1}{2}\alpha} + C$$ Where ha = top cover thickness f = allowable stress E = efficiency P = pressure C = corrosion allowance	9
Mixer	Number of stirrer	$$n = \frac{H\ liquid}{2 \times Da^2}$$ Where Da = impeller diameter	10

RESULT AND DISCUSSION

The reactor used is a Continuous Flow Stirred – Tank Reactor (CSTR) type reactor. The digestion reactors (R1 and R2) were operated at a temperature of 140°C and a pressure of 4 atm. The mole ratio of bauxite : NaOH and produces 99% sodium aluminate ($NaAlO_2$) in the liquid phase. The output stream from the digestion reactor will be separated by sedimentation between the solids (bauxite residue) from the sodium aluminate solution in the Deep Cone Thickener. There are two results from the thickener, namely underflow and overflow. The underflow in the form of bauxite residue (impurity) drops to the bottom of the settling tank which will later enter the waste treatment unit, and the sodium aluminate solution will overflow at the top of the Deep Cone Thickener which then flows into the precipitator to precipitate aluminum oxide trihydrate. ($Al_2O_3.3H_2O$) from sodium aluminate solution.

In the precipitation process using a filtrate precipitation reactor in the form of a solution of Sodium Aluminate ($NaAlO_2$) and a solution of Sodium Hydroxide (NaOH) which is fed using a pump. At this low temperature sodium aluminate $NaAlO_2$ will absorb water and form trihydrate aluminum oxide ($Al_2O_3.3H_2O$) which is insoluble in water so that it will precipitate into a solid.

The slurry that comes out of the Precipitation Reactor is flowed by a pump and washing water by a pump to a rotary drum vacuum filter to separate solids and liquids. Obtained mixture containing $Al_2O_3.3H_2O$ and water, and filtrate containing sodium hydroxide. Then the mixture is put into the kiln.

The Calcination process uses a Kiln which comes out of a rotary drum vacuum filter containing $Al_2O_3.3H_2O$ solids and a little water is fed using a Belt Conveyor into the kiln. The temperature inside the kiln is 1200 °C and this will cause the water complex bound to the crystals to decompose and evaporate so that $Al_2O_3.3H_2O$ will turn into α-Al2O3 solid. The Al_2O_3 concentration that comes out of the Kiln is around 99.9%. Process flow diagram and reactor layout for the production of Al_2O_3 from bauxite and sodium hydroxide solution is shown in figure 1.

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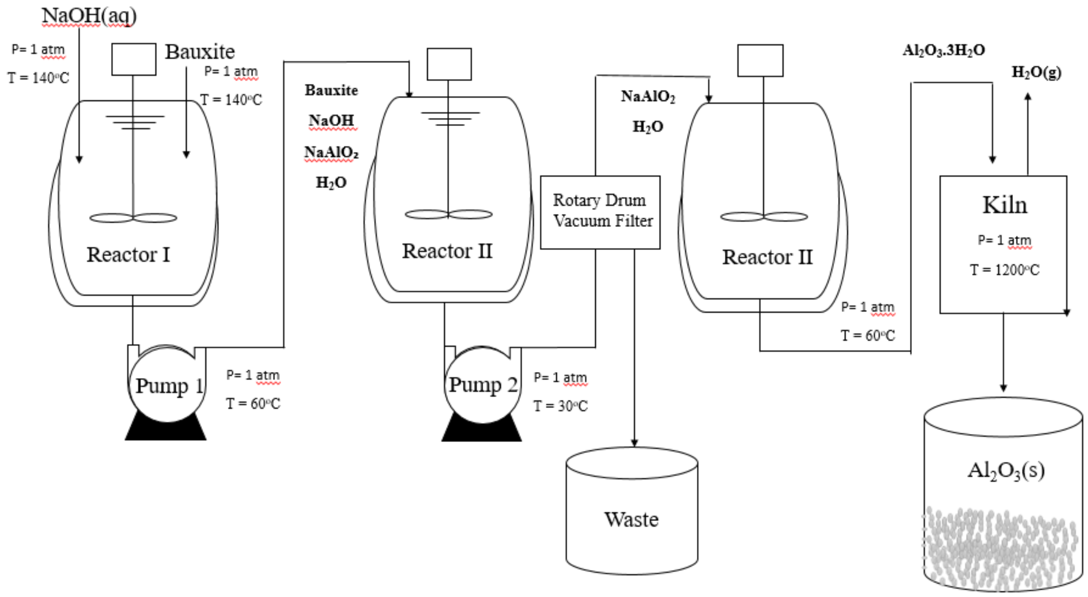

Figure 1. Prosess Flow Diagrams and reactor layout of the production of Al_2O_3 from bauxite and sodium hydroxide solution

The complete calculation results are shown in Table 2. The calculation shows that the first and second reactor has a volume of 2,9689 m^3 with a height of 5,0424 ft and requires one stirrer with a power of 50 Hp and the third reactor has a volume of 4,338723 m^3 with a height of 9,08474 ft and requires one stirrer with a power of 75 Hp.

No	Parameters	Result	
		R-I,II	RIII
1.	Reactant Volume (m^3)	354,6257	709,2514
2.	Reactor Volume (m^3)	2,9689	4,3387
3.	Reactor Height (ft)	5,0424	9,0847
4.	Design pressure (m)	1,2018	1,2018
5.	Top cover Height (m)	0,320	0,640
6.	Top cover Thickness (in)	0,25	0,50
7.	Stirrer Diameter (m)	0,512	1,024
8.	Stirrer Height (m)	0,102	0,204
9.	Number of Stirrer (pcs)	1	1
10.	Number of Blade (pcs)	6	6
11.	Degree of Blade	45°	45°
12.	Power of Blade (Hp)	50	75

CONCLUTION

Calculation of the specifications of Continuous Flow Stirred – Tank Reactor (CSTR) for the production of Al_2O_3 particles on an industrial scale. It is obtained with three reactors and three stirrers are required. The first and second reactor has a volume of 2,9689 m^3 with a height of 5,0424 ft and requires one stirrer with a power of 50 Hp, and the third reactor has a volume of 4,338723 m^3 with a height of 9,08474 ft and requires one stirrer with a power of 75 Hp. The calculations were performed using Microsoft Excel, but significant factor were not cpunted. Therefore, the computational calculation results of this study can be used as an overview in designing a reactor to produce Al_2O_3 nanoparticles from bauxite and sodium hydroxide solution on an industrial scale.

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