IMPLEMENTATION OF MATHEMATICAL EQUATION FOR CALCULATING ALUMINA EXTRACTION FROM BAUXITE TAILING DIGESTION

PENERAPAN PERSAMAAN MATEMATIKA UNTUK MENGHITUNG PERSENTASE EKSTRAKSI ALUMINA DARI PROSES EKSTRAKSI AMPAS BAUKSIT

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ABSTRACT

Research on bauxite tailing digestion using pressurized batch reactor at a feed capacity of 86.66 kg had been conducted. Bauxite with -150 mesh of particle size is reacted with 42.15 kg of caustic soda (433.49 g/l) at 140^oC for 1.0 to 2.5 hours using steam as heating media. Lime added are varied from 3 to 9 kg. After processing for a certain period of time, slurry product is transfered into a mixer. To evaluate percent extraction of Al_2O_3 from this process, the height of slurry level in the mixer, densities of the slurry, filtrat, and solid residue are measured and determined. The head sample of bauxite, filtrate and residue are analysed by using wet method to obtain Al_2O_3 content of each sample taken from the mixer. There are four equations that are used for obtaining the alumina extraction, namely :

V_{sl}=4.176x+15.83

Wsl=(4.176x+15.83)ρsl

S=(ρsl - ρl)/ (ρs - ρl) (ρs/ ρsl)*100%

E=[10 (4.176x+15.83) [1- (ρ_{sl} - ρ_l)/ (ρ_s - ρ_l)]*[c_l/Fx_F]%

The calculation results show that by increasing lime added into the slurry, percent yield of alumina extraction tend to decrease from 46.63% for 3 kg of lime to 15.84% by using 9 kg of lime. Whereas by varying reaction time between 1.0-2.5 hours, percent yield of alumina extraction are fluctuation in the range of 42.07-60.54%, and the highest result was obtanined for 1,5 hours of reaction time. By implementing those four equations above for evaluating the data, we do not need to weigh the slurry in the reactor.

Keywords: bauxite tailing, digestion, alumina extraction, mathematical model, Bayer process.

ABSTRAK

Penelitian pelarutan bauksit dengan menggunakan reaktor batch bertekanan pada kapasitas 86,66 kg umpan telah dilakukan. Bauksit berukuran butir -150 mesh direaksikan dengan 42,15 kg sodium hidroksida (konsentrasi 433,49 g/L) pada suhu 140^oC selama 1.0 sampai 2.5 jam menggunakan media pemanas uap air. Kapur yang digunakan divariasikan mulai 3 sampai dengan 9 kg. Setelah proses berlangsung dalam jangka waktu tertentu, produk sluri dipompa ke dalam Mixer. Untuk mengevaluasi persen ekstraksi Al_2O_3 dari proses ini, tinggi permukaan sluri dalam reaktor, densitas sluri, filtrat dan padatan residu diukur dan ditentukan. Umpan bauksit, filtrat, dan residu dianalisis menggunakan cara basah untuk menentukan kandungan Al_2O_3 dalam setiap percontoh yang diambil dari Mixer. Ada 4 persamaan yang digunakan untuk menghitung persen ekstraksi dari proses pelarutan yaitu :

V_{sl}=4.176x+15.83

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W_{sl}=(4.176x+15.83)ρ_{sl}
S=[(ρ_{sl} - ρ_l)/ (ρ_s - ρ_l) (ρ_s/ ρ_{sl})]*100%
E=[10 (4.176x+15.83) [1- (ρ_{sl} - ρ_l)/ (ρ_s - ρ_l)]*[c_l/Fx_F]%

Hasil perhitungan dengan menggunakan persamaan di atas menunjukkan bahwa penambahan kapur yang semakin tinggi memberikan persen ekstraksi alumina yang semakin rendah yaitu dari 46.63% dengan dosis kapur 3 kg turun menjadi 15,84% dengan penambahan kapur sebesar 9 kg. Sedangkan untuk variasi waktu reaksi antara 1-2,5 jam, persen ekstraksi alumina mengalami fluktuasi dalam rentang nilai 42,07-60,54%, dan hasil tertinggi dicapai dalam waktu 1,5 jam dengan persen ekstraksi alumina sebesar 60,54%. Dengan menerapkan keempat persamaan di atas untuk mengevalusi data, penimbangan sluri dalam reaktor tidak diperlukan.

Kata kunci: ampas bauksit, pemasakan, ekstraksi alumina, model matematika, proses Bayer.

List of Symbols :
V_{sl} is volume of slurry in the mixer (litre)
x is height of slurry level in the mixer (cm)
W_{sl} is weight of slurry in the mixer (kg)
S is solid percentage of slurry (%)
ρ_{sl} is density of slurry (kg/l)
ρ_s is density of residue (kg/l)
ρ_l is density of filtrate (kg/l)
C_l is concentration of Al_2O_3 in filtrate (g/l)
E is extraction of Al_2O_3 (%)

INTRODUCTION

Bauxite is a heterogeneous material principally composed of aluminum oxide minerals and some impurities minerals. It is usually comprised of gibbsite, alumino-goethite, hematite, kaolin, quartz, and minor boehmite (Pan, et all., 2012) and is being used in chemical, cement, refractory, abrasive, fertilizer, steel and other industries (Tariq, et all. 2014). There are some bauxite companies which have been operating in Indonesia such as PT. Aneka Tambang and PT. Harita. Those companies usually use open pit method to mine crude bauxite from its deposit in the earth. They use backhoe to dig crude bauxite and the product mine is then transferred by dump truck to washing plant area. Washing is one of methods that is usually used to upgrade alumina content of bauxite by separating primary mineral impurities like clay, silica, iron, and titanium that are attached on the surface of crude bauxite (Palmer, et all., 2009). Trommol screen is a common equipment used to wash and screen coarse bauxite from very fine particles size by supporting pressurized spray water. By using water spraying and screening, smaller particles attached on the surface of crude bauxite is easy to separate. Therefore, there are two products of washing, namely washed bauxite having +2mm of particle size with high content of alumina and tailing having –2mm of particle size with lower content of alumina. The amount of tailing resulting from crude bauxite washing is a lot, it is about 50% by weight of crude bauxite that is being washed. PT. Antam is now producing washed bauxite about 750,000 ton per year to supply *PT.* Indonesia Chemical Alumina that has being produced *chemical grade alumina* with a capacity of around 300,000 tons alumina per year using Bayer’s method. So, the amount of crude bauxite to be mined by PT. Antam is around 1,500,000 tons per year and this will generate tailing about 750,000 tons per year.

Up to now, this tailing is dumped into tailing pond and has not been utilized yet. So, it will endanger the environment if it is not handled properly. Besides, it needs very big space for preparing pond to collect tailing from bauxite washing, so it will be costly. In the effort to minimize the problem, Mineral and Coal Technology Research and Development Center has been trying to process tailing to become sodium aluminate solution that can be utilized as a raw material for polyaluminum chloride, alum, or synthetic zeolite production.

To make it easy and practices in carrying out research activities on tailing digesting, especially in evaluating the data obtained from research, a mathematical model is used to determine some parameter such as slurry volume, slurry weight, solid percentage, and percent extraction of alumina. This paper will discuss the result of the reasearch on digesting tailing from bauxite washing originited from Meliau, West Kalimantan, Indonesia.

Bayer's process is the only one technology applied all over the world for producing alumina economically. There are four-steps of processing to produce alumina from bauxite, namely digesting, filtering, precipitation, and calcination (Kopeliovich, 2012, Kontopoulos, et all., 1997). Fine bauxite (-150 mesh of particle size) is digested in pressurized reactor (autoclave) at certain temperature and pressure, depending on type of bauxite which is processed. Usually, the digesting temperature in the range of 140-160^oC for gibbsite type and 220-280^oC for bochmite type of bauxite. Chemical reaction occured in bauxite digestion is as follows (Donoghue, 2014, Reyner-Canham, et.all.,1996):

$$Al_2O_3.3H_2O + 2NaOH_{aq} \rightarrow Na_2O.Al_2O_3 + 4H_2O$$
(sodium aluminate)

In addition to dissolve alumina content, caustic soda will also react with reactive silica contained in the bauxite tailing as described in chemical reaction bellows (Palmer et al., 2009):

$$2NaOH + SiO_2 \rightarrow Na_2O.SiO_2 + H_2O$$
(sodium silicate)

Then sodium aluminate will react with sodium silicate with chemical reaction bellows:

$$Na_2O.Al_2O_3 + 2\ (Na_2O.\ SiO_2) + 4\ H_2O = Na_2O.Al_2O_3.\ 2SiO_2 + 2\ H_2O + 4\ NaOH$$
(*sodalite*)

Sodalite will combine with red mud to be wasted that should be managed properly. Based on a thermodynamic point of view, bauxite digestion primarily is controlled by alumina mineral phase, caustic concentration, and digestion temperature (Hond, et all., 2007).

In this research, tailing to be processed is belong to gibbsite type of bauxite, therefore the temperatur of digesting that has been used around 140^oC is suitable for this process. Product of digesting is slurry form containing sodium aluminate and red mud. By filterring using filter press, clear sodium aluminate solution is produced separated from cake of red mud (The International Aluminium Institute, 2012). To convert sodium aluminate into alumina trihydrate [$Al(OH)_3$] precipitate, for conventional method, seed of fine $Al(OH)_3$ is added into sodium aluminate solution during hydrolisys process that can achieve precipitation ratio of 55%. Hydrolysis is conducted at a certain temperature ; boehmite can be precipitated at the temperature above 90^oC for isothermal condition and between 70-90^oC for non isothermal condition. The yield of boehmite precipitation is 35 - 40% (Kontopoulos, et al., 1997). The alumina concentration in the supersaturated sodium aluminate solution is in between 80-200g/l with best value 132g Al_2O_3/l. Caustic concentration in the supersaturated sodium aluminate solution is varying between 50-250g/l with best value 120g/l (Kontopoulos, et al., 1997). By adding methanol, a proper temperature for sodium aluminate hydrolysis is about 64.5 °C with maximum equilibrium precipitation ratios is about 83% after 24 h and stated that the lower viscosity at higher temperature is a factor that enhances the yield and makes the effect of temperature is small (Zhang, et al., 2009).

The washed product of $Al(OH)_3$ is then dried and calcined at hight temperature in the range of 1010-1260^oC in a rotary kiln or fluidized bed calciners to drive off the molecules of hydrated water to become alumina: $Al_2O_33H_2O = Al_2O_3 + 3H_2O$ or $2Al(OH)_3 = 2Al_2O_3 + 3H_2O$ (Kopeliovich, 2012; Marsh, 2009, Kontopoulos, et al., 1997).

To improve Bayer's process performance, lime or its derivatives can be used to reduce caustic soda consumption, especially at higher temperatures. Lime increases the desilication efficiency of the bauxite digesting. In addition to reduce silica content in sodium aluminate solution, lime can also minimize impurities like carbonate, silica, and phosphor of this solution (Pan et al., 2012).

Sodium aluminate solution is most widely used in municipal drinking water and waste water treatment systems as coagulating agent to improve flocculation, and for removing dissolved silica and phosphates. It is also used in the paper industry, for fire brick production, alumina production and synthetic zeolites. In construction technology, sodium aluminate is employed to accelerate the solidification of concrete, mainly when working during frost.

METHODOLOGY

Bauxite used for the experiment is from Meliau, West Kalimantan having -150 mesh of particle size and having average chemical composition of Al_2O_3 27.89%, total SiO_2 50.79%, free SiO_2 39.49%, reactive SiO_2 11.3%, and Fe_2O_3 7.98%. Raw materials used are bauxite tailing (under size of bauxite washing by using rotary drum scrubber), caustic soda, lime and water. The mixture consisting of 86.66 kg bauxite tailing, 42.15 kg NaOH, 87.5 kg water and lime at certain weight are put into an autoclave. The mixture in the autoclave is then heated and contacted directly with steam generated from boiler. The steam having pressure about 4 atm and temperature around 140^oC are used for heating media. Variables observed include lime doses and reaction time. Lime doses vary from 3 to 9 kg for 86.66 kg of feed and reaction time varies from 1 to 2.5 hours (Table 1). After digesting process is finished, slurry product from autoclave is flown into the sump and then diluted with water before pumping into Mixer. Slurry level in the Mixer is then measured to calculate slurry volume in the Mixer. After that, the slurry in the Mixer is sampled and divided into two parts, one sample for filtering to get filtrate and red mud, another sample for physical analysis. Densities and alumina contents of all those samples including slurry, filtrate, and red mud are then determined. Using all data obtained, percent extraction of alumina can be calculated. There are four steps to obtain percent extraction of alumina, namely a) determination of slurry volume using equation (1); b) determination of slurry weight using equation (2); c) determination of solid percentage of the slurry using equation (3); and d) calculation of percent extraction of alumina using equation (4). Equipments used for conducting experiment consist of boiler, ball mill, sump, autoclave, mixer, and filter press (Figure 1). The flow diagram of experiment is shown in Figure 2. Firstly, bauxite tailing is ground into -150 mesh using ball mill, followed by digestion of bauxite tailing by using caustic soda in autoclave, after that transfering slurry of digestion product from autoclave into Mixer, finally filterring slurry by using filter press to get clear sodium aluminate solution separated from red mud. Mixer has a specification as follows : diameter 76.50 cm, height 157 cm, total volume 700 L.

RESULTS AND DISCUSSION

To determine percent extraction of Al_2O_3 from bauxite tailing digesting, some data should be collected, those are slurry volume, filtrate volume, slurry weight, solid percentage, densities of slurry, filtrate and residue. There are four equation to be used to calculate slurry volume, slurry weight, solid percentage, and alumina percent extraction that will be explained belows.

Determination of Mixer Volume

To determine Mixer volume at any height level, callibration method should be conducted. Firstly, empty a Mixer and acquire zero point in the system. Secondly, a certain volume of water is put into Mixer and write down the height of water level in Mixer. Thirdly, repeat it in this way until the relation between water volume and height water level along the height of Mixer is collected and then make a graph tabulation to get an equation.

For knowing slurry volume resulting from digesting bauxite with caustic soda using pressurized reactor, digested slurry product is pumped into Mixer where its volume has been callibrated. Mixer volume is a function of its height level as shown in Tabel 1. By plotting the height of slurry level versus slurry volume, it can obtain a stright line equation that is V_{sl}=4.176x+15.83 as shown in Figure 3, where Vsl is slurry volume and x is the height of slurry level in Mixer. From Figure 3, the slurry volume increases by the increase of height slurry level in Mixer. The highest slurry level in Mixer is 157 cm which correlates with slurry volume of 680 L. On the other hand, the height slurry level of 0 cm shows slurry volume of 20 L, it means that the bottom part of Mixer has volume of 20 L.

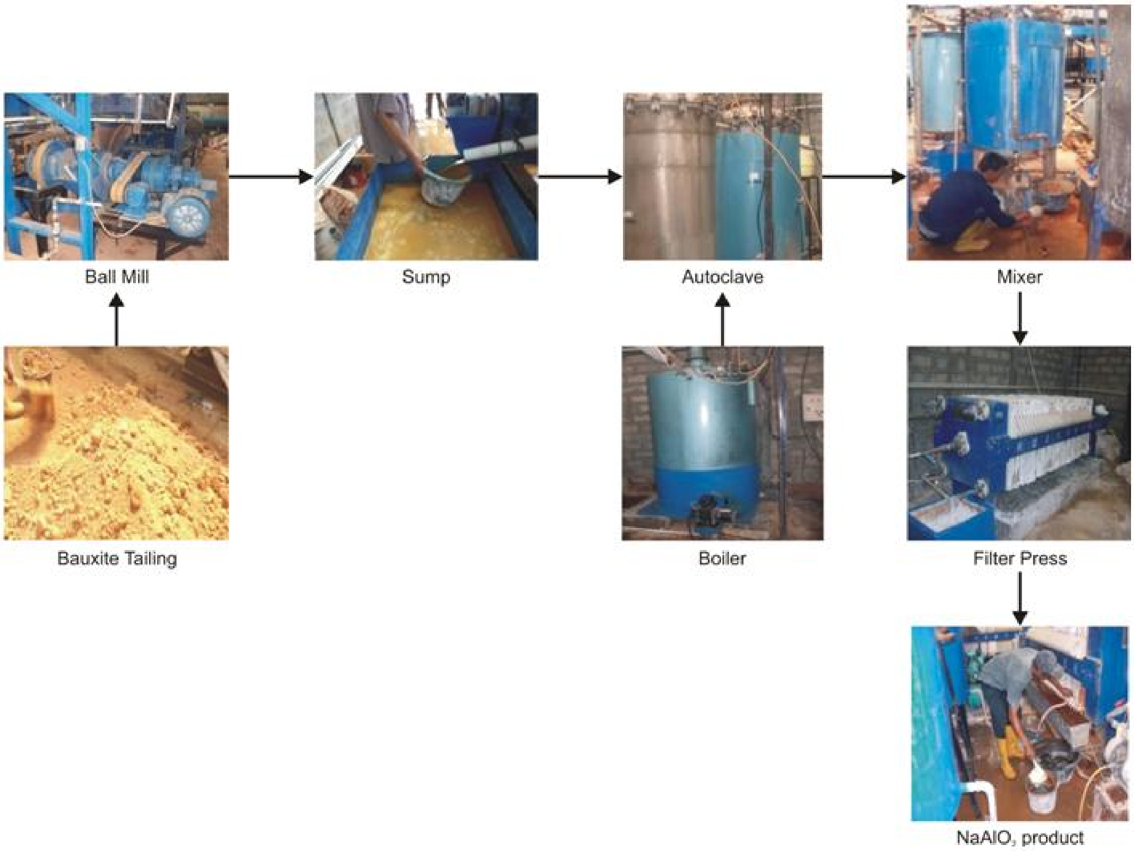

Figure 1. Equipment used for experiment

Tabel 1. Condition of digesting bauxite tailing

No. of the experiment	1	2	3	4	5	6	7	8	9
Reaction time (hour)	1	1	1	1	1	1	1.5	2	2.5
Lime (kg)	3.0	4.5	6.0	7.5	9.0	3.0	3.0	3.0	3.0
Weight of feed (kg)	86.66	86.66	86.66	86.66	86.66	86.66	86.66	86.66	86.66
Al_2O_3 grade of feed =xF (%)	27.89	27.89	27.89	27.89	27.89	27.89	27.89	27.89	27.89
NaOH used (purity 99%) (kg)	42.15	42.15	42.15	42.15	42.15	42.15	42.15	42.15	42.15
H_2O consumption (kg)	87.5	87.5	87.5		87.5	87.5	87.5	87.5	87.5
NaOH concentration (g/L)	433.49	433.49	433.49	433.49	433.49	433.49	433.49	433.49	433.49
Initial solid percentage (%)	40.56	40.56	40.56	40.56	40.56	40.56	40.56	40.56	40.56
Desilication condition:									
- Steam pressure (atm)	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3
- Temperature of slurry (^oC)	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60
- Reaction time (minute)	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20
- Duration from start to maximum pressure (minute)	45	45	45	45	45	45	45	45	45
Digesting condition:									
- Steam pressure (atm)	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
- Temperature of slurry (^oC)	120	120	120	120	120	120	120	120	120
- Reaction time (minute)	2	2	2	2	2	1	1.50	2.00	2.50

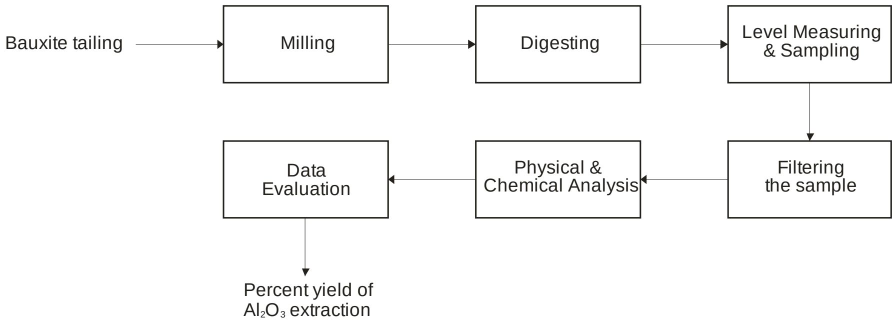

Figure 2. Flow sheet for bauxite tailing digesting and method for experimental data evaluation

Tabel 2. Relation between height of slurry level with volume of slurry in Mixer

Height slurry level (cm)	Volume of slurry (L)	Height slurry level (cm)	Volume of slurry (L)
157	680	81	350
155	670	79	340
153	660	76	330
151	650	74	320
149	640	72	310
147	630	69	300
145	620	66	290
143	610	63	280
141	600	61	270
138	590	59	260
135	580	56	250
132	570	53	240
129	560	51	230
127,5	550	49	220
125,5	540	46	210
123,5	530	44	200
121	520	42	190
118	510	39	180
116	500	37	170
114	490	34	160
111	480	31	150
109	470	29	140
107	460	27	130
104	450	25	120
102	440	22	110
99	430	20	100
97	420	18	90
95	410	15	80
92	400	13	70
90	390	10	60
88	380	8	50
85	370	6	40
83	360	3	30
		0	20

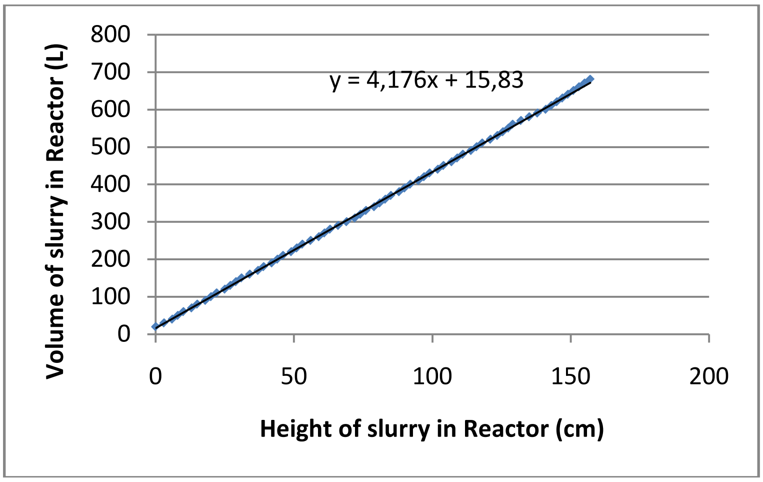

Figure 3. Relation between height of slurry level with slurry volume in Mixer

Determination of Slurry Volume in Mixer
Slurry level (x) in Mixer obtained from this experiment is shown in Table 2. By using equation : V_{sl}=4.176x+15.83, the slurry volume at any digesting condition can be determined. The complete data of the slurry volume are shown in Table 2.

Determination of Slurry Weight in Mixer
Slurry weight at a certain volume in Mixer can be calculated by multiplying slurry volume (V_{sl}) with slurry density (ρ_{sl}). So, the formula can be written down as follows: $W_{sl} = V_{sl}\ \rho_{sl.}$ Therefore : $W_{sl}=(4.176x+15.83)\rho_{sl.}$ The complete data of the slurry weight are shown in Table 3.

Determination of Solid Weight in Mixer
Solid weight can be obtained as follows: filtrate volume is slurry volume minus solid volume

$V_l = V_{sl}-V_s$
$W_s = W_{sl}- W_l$
$W_s = V_s\ \rho_s$
$W_{sl} = V_{sl}\ \rho_{sl}$
$W_l = V_l\ \rho_l$
$V_s.\rho_s = (V_{sl}\ \rho_{sl} - V_l\ \rho_l)$
$V_s.\rho_s = [V_{sl}\ \rho_{sl} - (V_{sl}-V_s).\rho_l)]$
$V_s.\rho_s = (V_{sl}\ \rho_{sl} - V_{sl}\ \rho_l + V_s\ \rho_l)$
$V_s\ (\rho_s - \rho_l) = V_{sl}\ (\rho_{sl} - \rho_l)$
$V_s = V_{sl}\ (\rho_{sl} - \rho_l)]/\ [(\rho_s - \rho_l)$
$W_s = [V_{sl}\ (\rho_{sl} - \rho_l)/\ (\rho_s - \rho_l)]\rho_s$
$W_s = [(4.176x+15.83)\ (\rho_{sl} - \rho_l)/\ (\rho_s - \rho_l)]\rho_s$

The complete data of the solid weight are shown in Table 3.

Determination of Solid Percent in Mixer (Oxana Fox, 2016**)**
$W_{sl} = V_{sl}\ \rho_{sl}$
Solid percentage (%) = (Solid weight/Slurry weight) x 100%
$S = W_s/W_{sl}$ x100 (%)

Equation of (2) and (3) are substituted to equation (4)
$S = [(V_{sl}\ (\rho_{sl} - \rho_l)/(\rho_s - \rho_l)\rho_s)/\ V_{sl}\ \rho_{sl}]$x100 (%)

The complete data of solid percentage of the slurry are shown in Table 2.

Determination of Percent Extraction
From the above equation is known:
$V_l = V_{sl} - V_s$
$V_s = V_{sl}\ (\rho_{sl} - \rho_l)/\ (\rho_s - \rho_l)$
$V_l = V_{sl} - [V_{sl}\ (\rho_{sl} - \rho_l)/\ (\rho_s - \rho_l)]$

$$V_l = (4.176x+15.83) - \left(\frac{(4.176x+15.83)\ (\rho_{sl} - \rho_l)}{(\rho_s - \rho_l)}\right)$$

The equation should be used to calculate percent yield of Al_2O_3 extraction as follows: The % yield of a reaction is the percentage of the product obtained compared to the theoretical maximum (predicted) yield calculated from the balanced equation (Faiers, 2015).

The predicted maximum theoretical yield can be get from a reacting mass calculation. The comparison of the actual yield and the theoretical maximum yield can be expressed as percentage yield.

$$\text{PERCENTAGE YIELD (E)} = 100 \times \frac{\text{ACTUAL YIELD (e.g. in grams, kg, tonnes)}}{\text{PREDICTED theoretical YIELD (same mass units as above)}}$$

In this case : E is alumina weight in filtrate is divided by alumina weight in feed times 100%

$E = (V_l c_l/1000)/(F x_F/100) x 100\%$
$E = 10 V_l c_l / F x_F$ (%)
Where:
V_l = volume of filtrate in Mixer (L)
c_l = concentration of Al_2O_3 in filtrate (g/L)
F = feed weight (kg)
x_F = Al_2O_3 grade in feed (%)
$V_l = V_{sl} - \{V_{sl} (\rho_{sl} - \rho_l)/ (\rho_s - \rho_l)\}$
$E = 10 V_l c_l / F x_F$ (%)
$E = [10 [V_{sl} - \{V_{sl} (\rho_{sl} - \rho_l)/ (\rho_s - \rho_l)\}*[c_l/F x_F]$ (%)
$E = [10 [4.176x+15.83) -[(4.176x+15.83) - \{(\rho_{sl} - \rho_l)/ (\rho_s - \rho_l)\}]*[c_l/F x_F]$ (%)

Where :
V_{sl} is volume of slurry in the mixer (litre)
x is height of slurry level in the mixer (cm)
W_{sl} is weight of slurry in the mixer (kg)
S is solid percentage of slurry (%)
ρ_{sl} is density of slurry (kg/l)
ρ_s is density of residue (kg/l)
ρ_l is density of filtrate (kg/l)
C_l is concentration of Al_2O_3 in filtrate (g/l)
E is extraction of Al_2O_3 (%)

The complete data of percent extraction of Al_2O_3 are shown in Table 3.

The experiment of bauxite tailing digesting with caustic soda was conducted at 140°C and pressure of 4 atm. By using four equations mentioned earlier. all data needed to calculate percent extraction of Al_2O_3 can be collected as shown in Table 2.

Based on Tabel 2. the lime doses were plotted againts percent extraction of Al_2O_3 and the result is shown in Figure 4. It can be seen that lime doses provide a significant effect to the extraction of Al_2O_3. Percent extraction of Al_2O_3 tend to decrease by the increase of lime doses. The value of percent extraction of Al_2O_3 is 50.75% by using 3 kg of lime. then decrease to 16.77% by using 9 kg of lime. The cause of this phenomena could be explained by some reactions that might occur in bauxite tailing digesting as follows:

Al_2O_3 contained in bauxite tailing is dissolved with NaOH to form $Na_2O.Al_2O_3$:
$Al_2O_3 . 3H_2O + 2 NaOH = Na_2O.Al_2O_3 + 4 H_2O$ ....(1)

Reactive silica is also contained in bauxite tailing. and lime was added as desilication agent for digesting process in this experiment, therefore it will be dissolved as well with NaOH and $Ca(OH)_2$ as follows:

$SiO_2 + 2 NaOH + Ca(OH)_2 = Na_2O. CaO.SiO_2 + 2H_2O$ ....(2)

Then both products of chemical reaction (1) and (2) will react as follows (Smith, P., 2009):

$Na_2O.Al_2O_3 + 2(Na_2O. CaO.SiO_2) + 2H_2O = Na_2O.2CaO.Al_2O_3 . 2SiO_2 + 4 NaOH$....(3)
$Na_2O.2CaO.Al_2O_3 . 2SiO_2$ will precipitate together with red mud.

So, based on both chemical reactions (2) and (3) the more lime added. the more sodium aluminate will react with lime to produce sodalite mixed with red mud. As a result. percent extraction of Al_2O_3 will decrease. This result is in line with the statement of Chen et.al. (2007) who stated that the higher reactive silica contained in bauxite tailing. the higher sodalite produced will be; on the other hand. percent exraction Al_2O_3 will decrese because of more sodium aluminate produced will react with sodium silicate to produce sodalite. In this research, bauxite tailing used for the experiment contains reactive SiO_2 11.3%. This content is reasonable high compared to the average content of 0,94-4,9% in the global bauxite (Alcoa, 2016), because this bauxite tailing contains clay mineral which has a high reactive silica content.

Tabel 3. Experimental results

No. of experiment	1	2	3	4	5	6	7	8	9
Reaction time (hour)	1	1	1	1	1	1	1.5	2	2.5
Lime (kg)	3.0	4.5	6.0	7.5	9.0	3.0	3.0	3.0	3.0
Height of slurry level (X)(cm)	44.8	43	48.95	48.09	40.29	44	42.5	34	50
Constant value of equation (a)	4.176	4.176	4.176	4.176	4.176	4.176	4.176	4.176	4.176
Constant value of equation (b)	15.83	15.83	15.83	15.83	15.83	15.83	15.83	15.83	15.83
Slurry volume $=V_{sl} = 4.176x+15.83$	202.91	195.40	220.25	216.65	184.08	199.574	193.31	157.814	224.63
- Slurry density (ρ_{sl}) (g/mL)	1.41	1.421	1.367	1.385	1.46	1.342	1.427	1.432	1.44
- Filtrate density (ρ_l) (g/mL)	1.23	1.22	1.2	1.17	1.22	1.24	1.26	1.24	1.21
- Red mud density (ρ_s) (g/mL)	2.52	2.38	2.52	2.52	2.52	2.52	2.77	2.69	2.69
- Al_2O_3 content in filtrate (C_l) (g/L)	64.55	59.29	38.25	30.6	25.5	65.70	85.1	89.9	53.6
- Al_2O_3 content in red mud (x_S) (%)	19.13	23.11	19.76	19.76	22.63	29.48	21.52	20.72	21.7
- Al_2O_3 content in feed (x_F) (%)	27.89	27.89	27.89	27.89	27.89	27.89	27.89	27.89	27.89
Dried weight of feed (W_F) (kg)	86.66	86.66	86.66	86.66	86.66	86.66	86.66	86.66	86.66
Slurry weight in Mixer (kg)									
Wsl=(4.176x+15.83)ρsl	286.11	277.66	301.08	300.07	268.76	267.83	275.85	225.99	323.47
Filtrate volume in Mixer (L)									
$V_l = V_{sl} - [V_{sl}(\rho_{sl} - \rho_l)/(\rho_s - \rho_l)]$	174.60	161.54	192.38	182.15	150.10	183.67	171.93	136.92	189.72
Red mud weight in Mixer (kg)									
$W_s = [(4.176x+15.83)(\rho_{sl} - \rho_l)/(\rho s - \rho l)]\rho s$	71.35	80.58	70.22	86.95	85.64	40.08	59.22	56.21	93.90
Solid percentage in Mixer (%)									
$S = [(V_{sl}(\rho_{sl} - \rho_l)/(\rho_s - \rho_l)\rho_s)/V_{sl}\rho_{sl}] \times 100$ (%)	24.94	29.02	23.32	28.98	31.87	14.96	21.47	24.87	29.03
$E = Al_2O_3$ extraction (%) =(Vl*Cl/Wf*xF)*100%	46.63	39.63	30.45	23.06	15.84	49.93	60.54	50.93	42.07

The effect of reaction time on the percent extraction of Al_2O_3 is shown in Figure 5. In this research. bauxite tailing (-150 mesh) was digested with NaOH at the 140°C and pressure 4 atm using steam as heating media. From Figure 4, it can be seen that percent extraction of Al_2O_3 tend to fluctuate in the range of 44.29-62.79% by varying reaction time between 1.0-2.5 hours in which 1.5 hours is the highest value. The decrease of Al_2O_3 extraction by the increase time reaction above 1.5 hours may be caused by sodium and/or calcium silicate occured during digesting process react with sodium aluminate solution to form sodalite ($Na_2O.2CaO.Al_2O_3.\ 2SiO_2$) as explained above. So. the longer reaction time, the higher the amount of sodium aluminate that react with sodium silcate will be. As a result, extraction of Al_2O_3 will decrease.

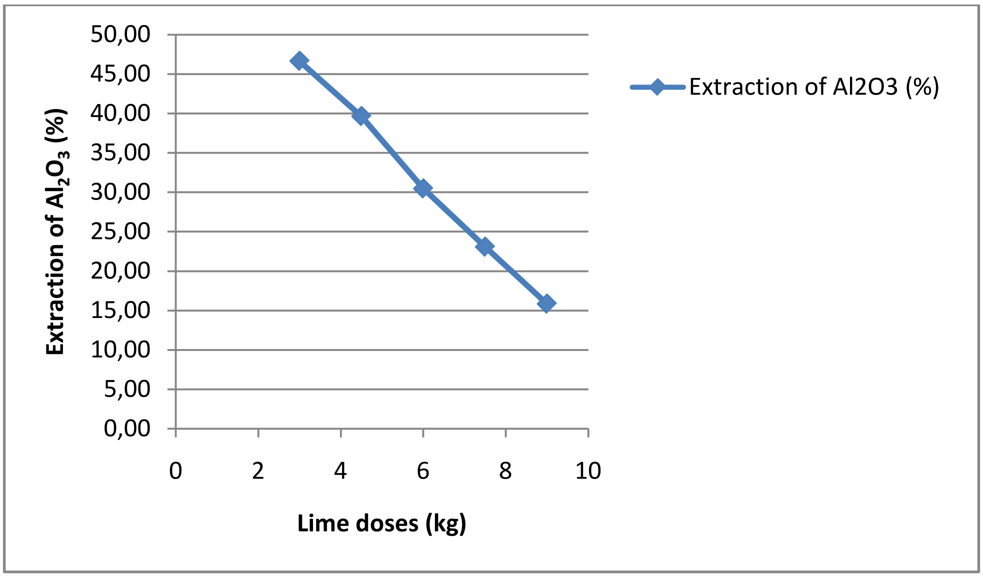

Figure 4. The relation between alum doses versus percent extraction of Al_2O_3

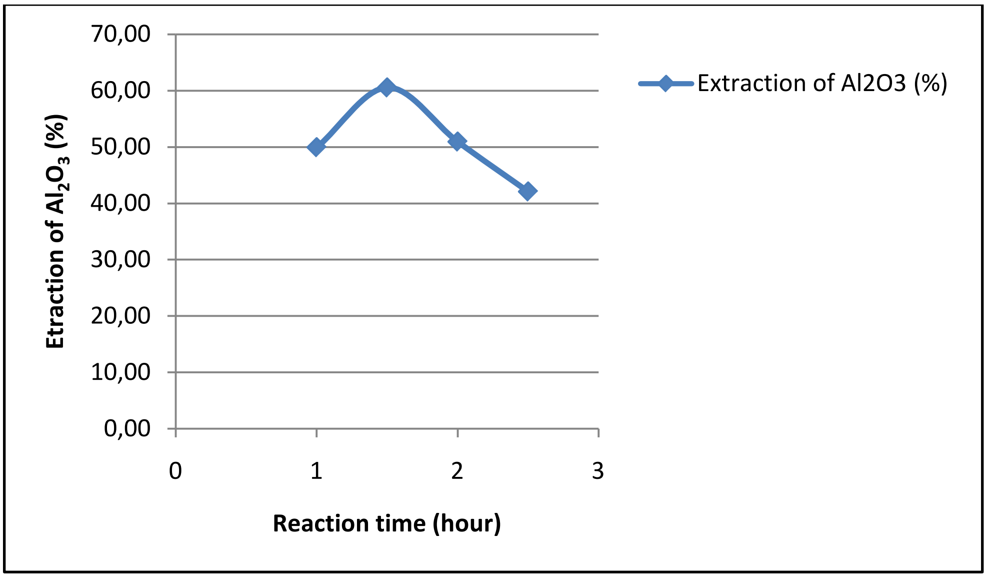

Figure 5. The relation between reaction time versus percent extraction of Al_2O_3

CONCLUSION

Percent extraction (yield) of alumina from crude bauxite digesting using caustic soda at 140^{o}C and pressure 4 atm can be determined by using four equations without weighing of the slurry obtained from digestion process. Those four equation are V_{sl}=4.176x+15.83; W_{sl} = (4.176x + 15.83)ρsl; S=[(V_{sl} (ρ_{sl} - ρ_l)/(ρ_s - ρ_l) ρ_s) / V_{sl} ρ_{sl}] x100 (%) and E=[10 [4.176x+15.83) -[(4.176x+15.83) - {(ρ_{sl} - ρ_l)/ (ρ_s - ρ_l)}]*[c_l/Fx_F] (%). Some data needed for determination of percent yield of alumina extraction are densities of slury. filtrate. and red mud as well as alumina contents. The first obtained data is slurry volume, followed by slurry weight. slurry solid percentage. and finally calculation of percent yield of alumina extraction. From evaluation of digesting process. it can be concluded that by increasing lime added into the process. percent yield of alumina extraction obtained tend to decrease from 50.75% by using 3 kg of lime to 16.77% by using 9 kg of lime. Whereas, by varying reaction time between 1.0-2.5 hours, percent yield of alumina extraction tend to fluctuate in the range of 44.29-62.79% in which 1.5 hours of reaction time is the highest percent yield. By implementing four equation described above, weighing of the slurry in Mixer is not needed.

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