INDONESIAN MINING JOURNAL Vol. 17, No. 2, June 2014 : 98 - 112

KINETICS ANALYSIS FOR ALUMINUM DISSOLUTION OF WEST KALIMANTAN BAUXITE THROUGH DIGESTION PROCESS

ANALISIS LAJU REAKSI PELARUTAN ALUMINUM DARI BAUKSIT KALIMANTAN BARAT

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ABSTRACT

Kinetics model was developed for aluminum dissolution of West Kalimantan bauxite based on shrinking core model. A series of digestion tests was carried out to study aluminum dissolution from the ore sample with particles size distribution of 100% passing 60 mesh in 129 gpL of NaOH. The digestion tests were conducted at 140; 150 and 160°C under stirring speed of 500 rpm. The experimental result shows that after a certain period of digestion time, thus aluminum dissolution was fluctuated due to the formation of DSP as a result of the reaction of sodium aluminate solution with reactive silica in the ore. Aluminum dissolution data were analyzed and treated with Matlab software to predict time required for complete dissolution (τ). By using the obtained τ, hence fittings experimental data using 3 different rate-determining steps of kinetics models (i.e. interface reaction, film diffusion and diffusion through solid product layer) and dummy data were performed. Prediction of the rate-determining step of aluminum dissolution was then made by evaluating the value of square correlation coefficient (R2) from the regression equation of the models and then obtained the activation energy. The kinetics study which considers aluminum precipitation during digestion reveals that alumina dissolution mechanism is altered from interface chemical reaction with energy activation (Ea) of 29.57 kcal/mole to difussion through reaction product (ash) layer (Ea=2.77 kcal/mole).

Keywords : bauxite, aluminum, kinetics model, activation energy, desilication product (DSP).

SARI

Pengembangan model laju reaksi pelarutan aluminium dari bauksit Kalimantan Barat didasarkan pada model penyusutan inti. Beberapa percobaan pelarutan telah dilakukan terhadap percontoh bijih yang berukuran partikel 100% lolos 60 mesh dalam larutan NaOH konsentrasi 129 gpl. kecepatan pengadukan 500 rpm pada suhu 140; 150 dan 160°C. Hasil percobaan menunjukkan bahwa laju pelarutan aluminium fluktuatif seiring bertambahnya waktu yang disebabkan oleh terbentuknya DSP sebagai hasil dari reaksi antara larutan sodium alumina dengan silika reaktif di dalam bijihnya. Data laju pelarutan aluminium dianalisa dan diolah menggunakan program Matlab untuk menentukan waktu pelarutan sempurna yang dinyatakan dalam τ*. Data* τ *yang diperoleh digunakan untuk menyesuaikan data percobaan dengan 3 model laju pengendali reaksi (yaitu reaksi antar muka, difusi lapisan tipis dan difusi melalui lapisan produk) menggunakan data dummy. Penentuan laju pengendali reaksi pelarutan aluminium dilakukan dengan mengevaluasi nilai koefisien korelasi (R2) hasil regresinya maka diperoleh nilai*

Received : 28 July 2013, first revision : 22 October 2013, second revision : 06 March 2014, accepted : June 2014

energi aktivasi. Studi laju reaksi yang mempertimbangkan terjadinya pengendapan aluminium selama pelarutan terungkap bahwa mekanisme laju reaksi pelarutan pada awalnya cenderung dikendalikan oleh reaksi antar muka dengan energi aktivasi (Ea) = 29,57 kcal/mole, kemudian dengan bertambahnya waktu terjadi reaksi difusi melalui lapisan produk (abu) (Ea = 2,77 kcal/mole).

Kata kunci : bauksit, Aluminium, kinetika, model, energi aktivasi, produk desilikasi (DSP).

INTRODUCTION

The Bayer process has been the only process for alumina production that has been used in such industries since hundred years up to the present. The steps of Bayer process consists of digestion, clarification, precipitation and calcination to produce alumina powder with Al_2O_3 content >98%. Based on type of alumina-bearing minerals, there are three minerals type of bauxite such as gibbsite, boehmite and diaspore (Bardossy and Aleva, 1990). Indonesia's bauxite mostly contains gibbsite and it requires relatively low digestion temperature for dissolving the alumina. Digestion is the core of Bayer process, which determine the yield of alumina. There are two main reactions occur during the digestion namely reaction of gibbsite with NaOH and reaction of kaolinite (for lateritic bauxite) with NaOH as follows:

$$Al_2O_3.3H_2O + 2NaOH \rightarrow 2NaAl(OH)_4 \text{ .... } (1)$$

$$Al_2O_3.SiO_2.H_2O + 4NaOH \rightarrow 2NaAlO_2 + Na_2SiO_3 + 3H_2O \text{ .... } (2)$$

Aim of this study is to understand that digestion process involves heterogenous reaction of liquid reactant of NaOH and solid phase of bauxite ore. Both reactions show aluminum dissolution in digestion, while some of sodium aluminate ($NaAlO_2$) will further react with sodium silicate (Na_2SiO_3) as stated in reaction 3 (Smith, 2009). The reaction show that some dissolved aluminum has precipitated and reduced dissolved aluminum concentration. Therefore, this study would consider steps of reaction rate that would influence all of the process reactions.

$$6Na_2SiO_3 + 6NaAl(OH)_4 + Na_2X \rightarrow Na_6[Al_6Si_6O_{24}].Na_2X + 12NaOH + 6H_2O \text{ .... } (3)$$

Kinetics of alumina dissolution can be approached with a prominent shrinking spherical core (SCM) model. According to Levenspiel (1999), there are three stages that can determine the rate of reaction according to the SCM. The following are the stages that can determine the rate of reaction according to the SCM and the relevant model for each stage:

1. Diffusion rate through fluid film on the surface particle:

$$\frac{t}{\tau} = \left(\frac{r}{R}\right)^3 = \alpha \text{ .... } (3)$$

2. Diffusion through solid product layer to the surface of unreacted core

$$\frac{t}{\tau} = 1 - 3(1-\alpha)^{\frac{2}{3}} + 2(1-\alpha) \text{ .... } (4)$$

3. Chemical reaction

$$\frac{t}{\tau} = 1 - (1-\alpha)^{\frac{1}{3}} \text{ .... } (5)$$

in which t is leaching time, rc is radius of unreacted core, R is radius of particle, τ is time required for complete conversion (at rc = 0) and α is conversion at time t (mole fraction of reacted components).

The plot of time t against the right side of the Equations (3), (4) and (5) will result in a linier correlation with a slope of being the value of τ. Once the τ value is known, we can determine reaction rate constant k or diffusion rate constant, De, dependent on the rate-determining step. Following the derivation by Levenspiel (1999), the correlations between those two constants with τ are formulated as follows:

$$\tau = \frac{\rho_b R^2}{6_b D_e C_{Ag}} \text{ .... } (6)$$

$$\tau = \frac{\rho_b R^2}{b k C_{Ag}} \text{ .... } (7)$$

where ρ is mineral density, R is the initial radius of the mineral particle, b is reaction coefficient for solid reactant and CAg is concentration of reactant in the bulk solution, k is rate constant and De is effective diffusion coefficient of reacting species.

To support the curve-fitting of the kinetic models and the experimental data, the rate-determining step can also predicted by the level of activation energy for the reaction. Following Habashi (1969) if the value of activation energy was within the range of 1-3 kcal/mole, then the process rate will be typically controlled by diffusion, while for activation energy > 10 kcal/mole will be typically controlled by chemical reaction. Furthermore, if the value of activation energy was in the range of 5 – 8 kcal/mole, the reaction rate will be controlled both by diffusion and chemical reaction (intermediate rate control). The activation energy (Ea) value can be determined from the slope of linier regression line of the plot of ln k or ln De versus1/T, in which T is absolute temperature of the process. Based on Arrhenius equation, the slope of the plots is the values of -Ea/R, thus the value of Ea can be determined from the slope of the plots for a known value of ideal gas constant (R).

The dissolution of gibbsite has been investigated by several researchers and there was no single agreement of the rate-determining step for the gibbsite dissolution. Some researchers considered diffusion as rate-determining step, and the others supposed that chemical reaction is the rate-determining-step. Pereira, et.al (2009) have investigated aluminum dissolution behaviour from gibbsite ore in 1.2 – 2.5 moles/L NaOH solution at 60 - 100°C and proposed the following equation for the rate of Al dissolution:

$$\frac{dC_{Al}}{dt} = k\left(1 - \frac{C_{Al}}{C^{o}_{gibbs}}\right)^{\frac{2}{3}} C_{OH^-} \quad \ldots\ldots\ldots\ldots (8)$$

in which CAl is dissolved aluminum concentration, k is rate constant, Cogibbs is initial aluminum content in gibbsite and C_{OH^-} is hydroxide ion concentration. Pereira (2009) reported the activation energy of 110kJ/moles (26.24 kcal/moles) based on his investigation results.

Bao and Nguyen (2010) suggested that aluminum dissolution from gibbsite ore is controlled by diffusion through solid product layer on the surface of unreacted core and proposed the following model for the rate of Al dissolution:

$$\frac{dC_{Al}}{dt} = \frac{D_e'}{\left(\left(1 - \frac{C_{Al}}{C^{o}_{gibbs}}\right)^{-\frac{1}{3}} - 1\right)} C_{OH^-} \quad \ldots\ldots\ldots\ldots (9)$$

These researchers used Pereira’s experimental data to confirm the fitness of the model with experimental data and the result showed that the model is not fit due to precipitations of parts of alumina during digestion to form sodium-alumino-silicate. To consider the influence of alumina precipitation during digestion, the following model for aluminum dissolution rate is proposed:

$$\frac{dC_{Al}}{dt} = k\left(1 - \frac{C_{Al}}{C^{o}_{gibbs}}\right)^{\frac{2}{3}} C_{OH}\left(C^{o}_{gibbs} - C^{\infty}_{gibbs} - C_{Al}\right) \quad \ldots\ldots\ldots\ldots (10)$$

in which C°gibbs is aluminum content in residue.

The above mentioned investigations done by Pereira (2009) as well as Bao and Nguyen (2010) used gibbsitic bauxite that was carried out at atmospheric pressure under temperature variations of 60-100°C. Grenman et al, (2010) conducted digestion tests of boehmite ore at atmospheric pressure and temperature range of 60 – 85°C by using 2 and 6 M of NaOH solution and reported that the kinetics of aluminum dissolution is controlled by interface chemical reaction. Kinetics study of boehmitic bauxite digestion at high pressure was performed by Li et al (2011), in which boehmite was syntesized from pure gibbsite and diaspore concentrate and mixed with 220 g/L NaOH solution. The mixture was put in gold crucible and heated at temperature range of 20 – 250°C under heating rate of 10°C/minute. Differential scanning calorimetry (DSC) was performed to generate DSC curves. Li et.al (2011) reported that aluminum dissolution is controlled by chemical reaction with activation energy of 79.187 kJ/mole. This experiment was done in pressurized reactor as well as industries. Hence, kinetic analysis on determining the rate-controlling step is important in order to know, which major variable influence the pressurized digestion process.

EXPERIMENTAL

The typical bauxite ore sample was originally derived from West Kalimantan, Indonesia. The sample was crushed, milled and classified to prepare the particle size distribution of 100% passing 60 mesh. Oxide composition of the sample was analysed chemically using Atomic Absorpstion Spectrophotometry (AAS). The oxides content of the ore sample was determined to calculate sodium hydroxide NaOH concentration required for the digestion. The predominant minerals in the ore was characterized by X-Ray Diffraction (XRD) analysis. Furthermore, the elemental distribution and morphology of the bauxite as well as the digestion residue were observed by Scanning Electron Microscope (SEM) and X-Ray mapping.

A Series of digestion tests was carried out in 2-litres Autoclave under variations of temperature and time. The digestion tests were conducted in 129 gpL NaOH solution against 200 grams of bauxite sample, which is equal to 1.5 times of stoichiometric moles ratio of NaOH to the contents of Al_2O_3 and reactive SiO_2. The digestion temperatures were varied at 140; 150; and 160°C. The digestion tests were conducted at 1; 3; 5; 15; 30; 45 and 60 minutes. All experimental works were done at a constant stirring speed of 500 rpm.

Sodium aluminate solution produced from the digestion process was analyzed for dissolved aluminum concentration by AAS, while dissolved silica was measured by gravimetric analysis. Aluminum extraction and converted fraction (α) of aluminum and silica as a function of time at various conditions were calculated. Based on the time dependent data of aluminum dissolution, thus the time for complete conversion (τ) was determined by extrapolation of the data using Matlab software. Afterward, fittings of experimental data with dummy data using SCM models (Equation 3-5) were performed for certain τ value. Prediction of the rate-determining step of aluminum dissolution was made by evaluating the value of square correlation coefficient (R^2) of the regression equation and calculated activation energy from the investigation results at temperatures of 140,150 and 160°C.

RESULTS AND DISCUSSION

Characteristic of the Ore Sample

XRD analysis of the ore sample detects gibbsite ($Al_2O_3.3H_2O$) as the dominant mineral, along with several minerals impurities of goethite (FeOOH), hematite (Fe_2O_3) and quartz (SiO_2) are also detected as illustrated in Figure 1, while chemical composition of the bauxite sample is presented in Table 1. The chemical composition analysis shows the ratio of Al to reactive Si is higher than 6.25, which indicates the ore sample can be classified as economically viable ore (Smith,

Table 1. Chemical composition of typical bauxite sample

Oxides	Weight percentages (%)
Al_2O_3	53.8
SiO_2 (total)	7.06
SiO_2 (free)	4.91
SiO_2 (reactive)	2.15
Fe_2O_3	5.52
Na_2O	0.28
K_2O	0.049
CaO	0.059
MgO	0.029
TiO_2	0.51
P_2O_5	0.031
LOI	28.2

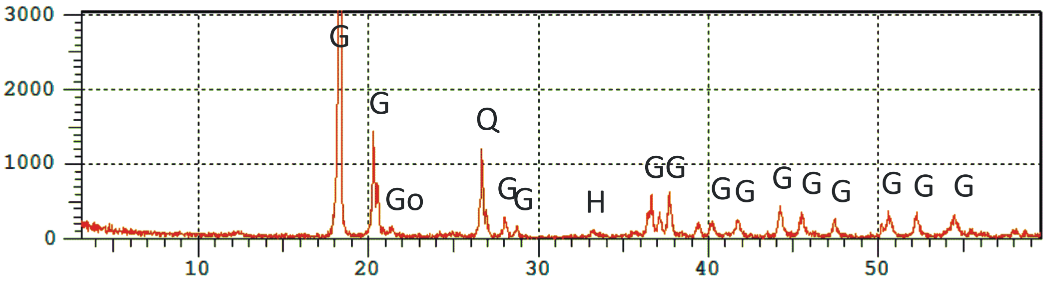
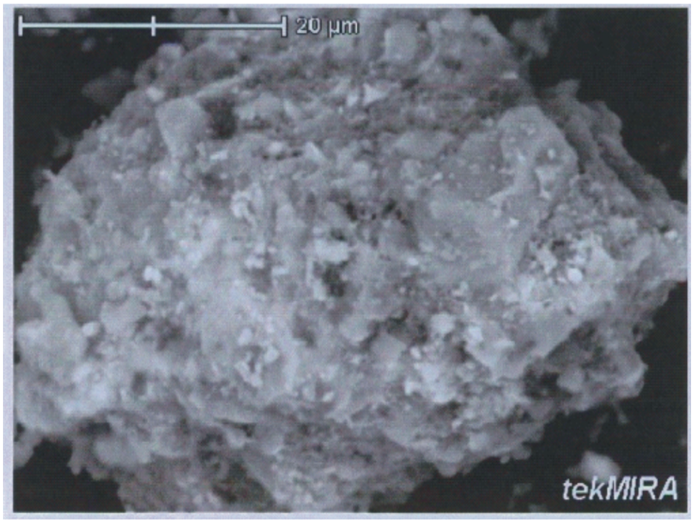
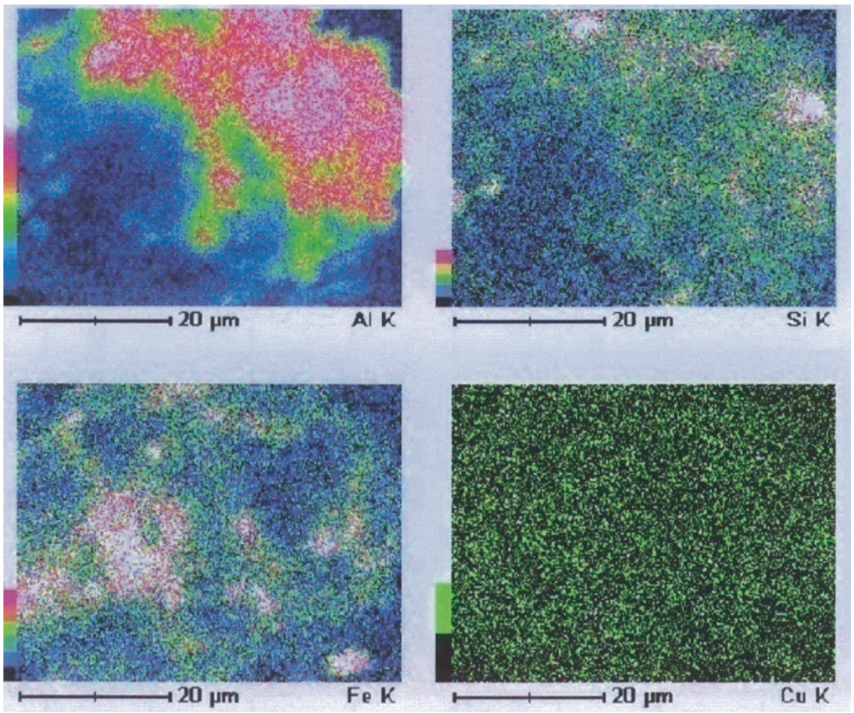


Figure 1. XRD pattern of bauxite sample



(a)



(b)

Figure 2. (a) SEM micrograph of the ore particle and (b) X-Ray mapping analysis of the ore sample

2009) for Bayer process. Morphology of the ore particles characterized by SEM and results of X-ray mapping analysis are illustrated in Figure 2. For kinetics study, the ore particle is assumed to be spherical. The SEM and X-Ray mapping analysis show that Al is the major element in ore, while Fe and Si are the dominant impurities while Cu present as noises.

Effect of Temperature

Profiles of dissolved Al concentration with time for digestion tests at temperatures of 140, 150 and 160°C under initial NaOH concentration of 129 gpL is shown in Figure 3. It can be seen that dissolved Al concentration increases until a certain level after a certain digestion time in which after

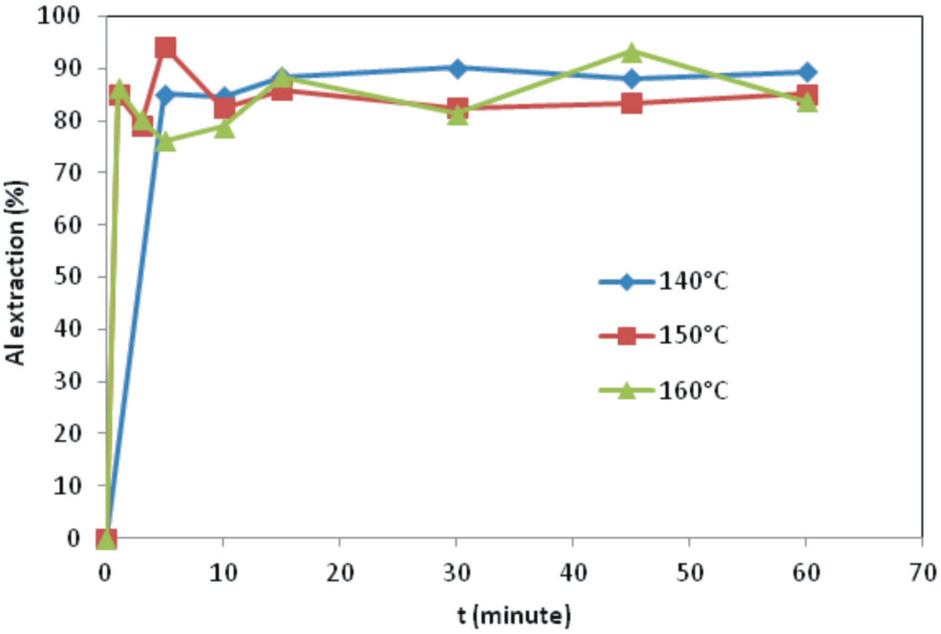


Figure 3. Dissolved Al concentration with time for digestion tests at various temperatures

this time the dissolved Al fluctuates by time.,The same behavior was observed at different temperature. An increase of dissolved Al concentration is associated with Al extraction,from,gibbsite and kaolinite according to Reaction 1 and 2. After a certain period of time, sodium silicate which is formed by the reaction of kaolinite with sodium hydroxide solution (Reaction 2) starts to react with sodium aluminate solution and produces desilication product (DSP) such as sodalite as described by Reaction (11). Reaction of sodium silicate (Na_2SiO_3) with sodium aluminate leads to the decrease of Al concentration by time as demonstrated by the digestion test results in Figure 3. Refers to Smith (2009) sodalite is one of several mineral phases produced by silica precipitation from the digestion solution known as desilication product (DSP).

$6Na_2SiO_3 + 6NaAl(OH)_4 + Na_2X \rightarrow Na_6[Al_6Si_6O_{24}].$
$Na_2X + 12NaOH + 6H_2O$ ....(11)

Thus, besides Al dissolution, the other aspect to be concerned is SiO_2 dissolution that would has consequences on NaOH consumption and alumina recovery. The digestion tests showed that dissolved SiO_2 concentrations were less than 0.6 g/L, which comply commercial application in industries (Habashi, 1997) and even below the best condition suggested of 0.2 g/L. Profiles of dissolved SiO_2 concentration with time for digestion tests at various temperatures are illustrated in Figure 4. At the beginning, dissolved SiO_2 concentration increases which is associated with silica dissolution from kaolinite mineral (Reaction 2). After certain period of time, dissolved silica concentration decreases due to precipitation of DSP through reaction (11).

Kinetics Analysis of Aluminum Dissolution

Kinetics analysis was performed to determine the rate-determining stage that control Al dissolution. Regression of experimental data with certain equation was carried out by using Matlab software. After the regression equation is obtained then the equation was used to determine the time dependant for complete conversion (τ) at which no more change of the dissolved Al occured. The next step is fittings of t/τ vs. $1-\alpha$ values between experimental data and dummy data of obtained τ. The fittings of t/τ vs $1-\alpha$ between experimental data and dummy data for temperatures of 140, 150, and 160°C are presented in Figure 5.

The fittings of t/τ vs $1-\alpha$ between experimental and dummy data at such temperatures of 140, 150 and 160°C in Figure 5 shows that the fittest kinetics model to experimental data is diffusion through solid product (ash) layer. Linier regressions of

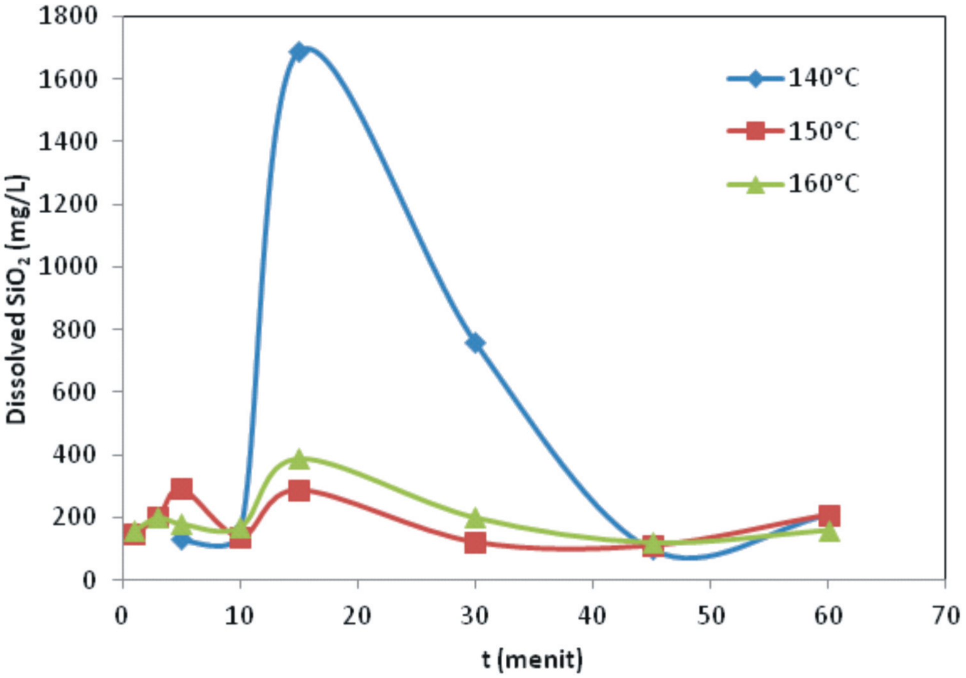


Figure 4. Profiles of dissolved SiO_2 concentration with time for digestion tests at various temperatures

experimental data with the three different kinetic models (Equation 3-5) are made for three different temperatures and the results are presented in Figure 6-8. Prediction of the rate-determining step of aluminum dissolution was made by evaluating the value of square correlation coefficient (R^2) of the regression equation. The R^2 value which is equal or closest to 1 indicates the better relation of Al dissolution data with the model. As the results of curve fittings between dummy data using three models and the experimental data, thus the linier regression of experimental data with the three different kinetic models indicated that the kinetics of Al dissolution is controlled by diffusion through solid product (ash) layer.

Slope of the linier regression line represents the value of τ. The values of R^2 and τ for linier regressions of experimental data in terms of three different temperatures with the three different kinetic models are summarized in Table 2. From the value of τ, hence effective difussion constant (D_e) for three digestion temperatures can be determined and the results are presented in Table 3. After the values of D_e are obtained, plotting of ln D_e versus 1/T were made and provide linier correlation with the slope being the value of E_a/R as can be shown in Figure 9. It was found that E_a value for Al digestion in 160 gpL NaOH under stirring speed of 500 rpm is 2.21 kcal/mole, which is in the range of typical kinetics controlled by diffusion. The value of this activation energy supported the evidence that Aluminum dissolution is controlled by diffusion through solid product (ash) layer as already indicated by curve fitting results and the values of R^2 of the linier regression equation of the experimental data to the three kinetic models used. The constant in the regression equation for the plot of ln De versus 1/T represents the value of ln Do, hence the value of Do can be determined. Based on the regression equation for ln De versus 1/T, the value of ln Do is 39.74, thus Do is 5,5098. 10^{-18} and the diffusion rate through ash layer on the surface of unreacted core can be expressed as De = 5,5098 . 10^{-18} . $e^{-1110,08/T}$.

Digestion processing rate is not controlled by film diffusion that means the stirring rate of 500 rpm is enough to create shorten distance between NaOH solution film layer and gibbsite particle. The interface chemical reaction does not control the digestion process which indicates that the reaction rate of alumina dissolution is likely faster at the temperature range of 140 -160 °C. Meanwhile, ash diffusion was found to control the reaction kinetics because of the formation of DSP on the surface of unreacted core as the product of the reaction between sodium silicate and sodium aluminate (reaction 3). To accelerate reaction kinetics, the reactive silica content in bauxite should

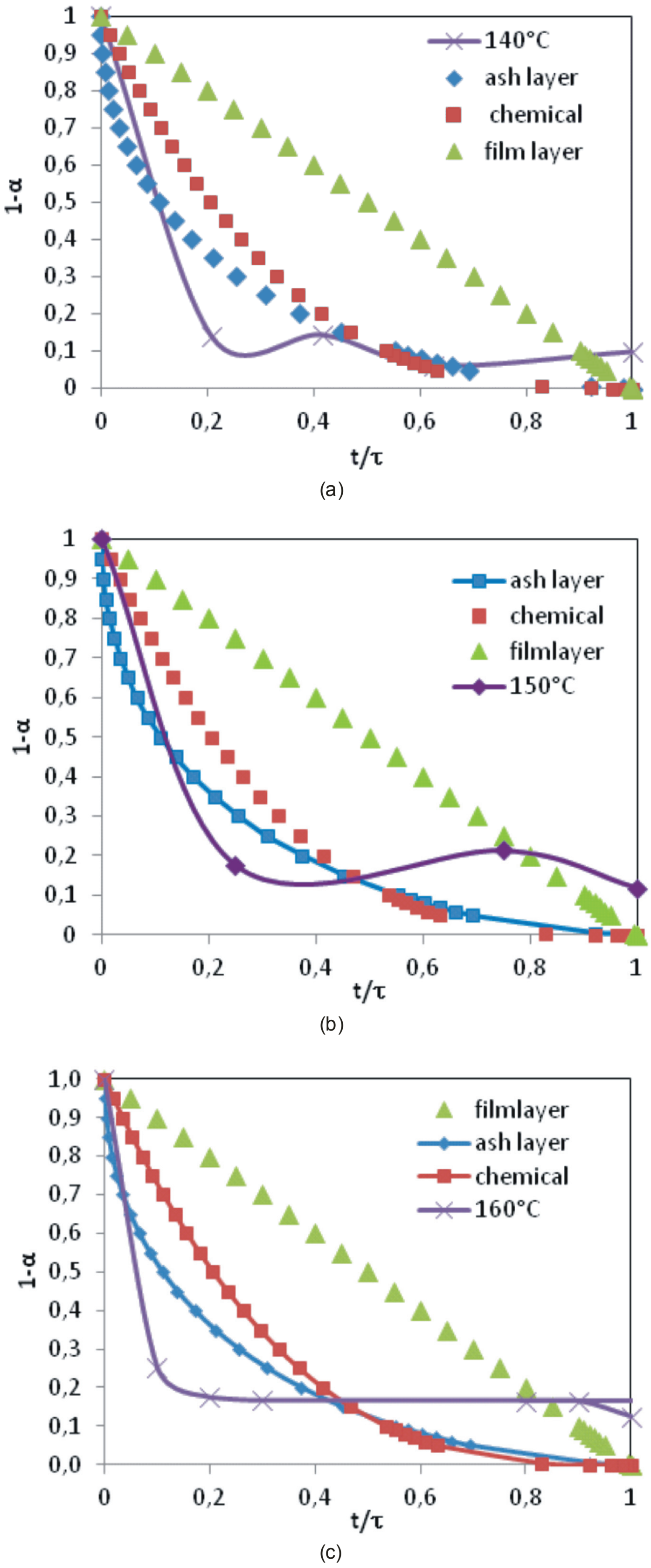


Figure 5. Fittings of t/τ vs. 1-α between experimental data and dummy data for digestion tests at (a) 140°C, (b) 150°C and (c) 160°C

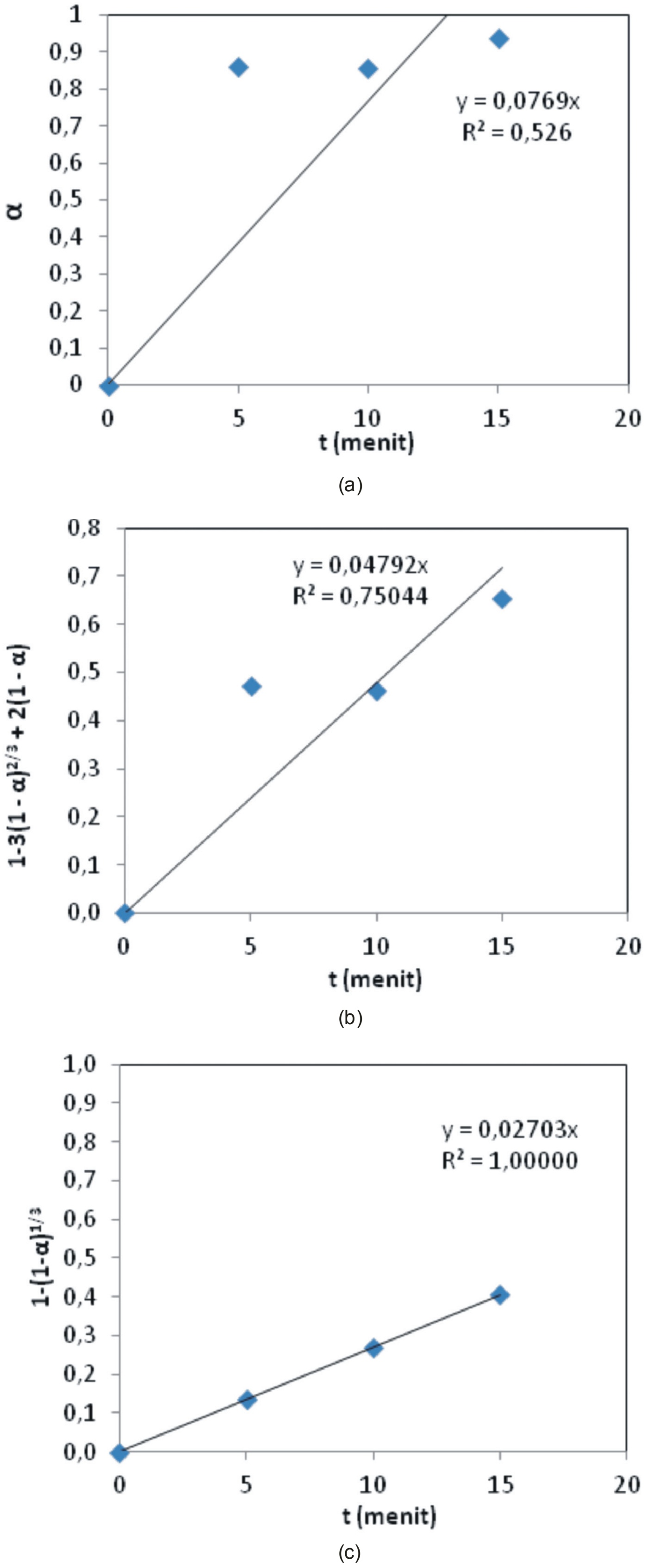
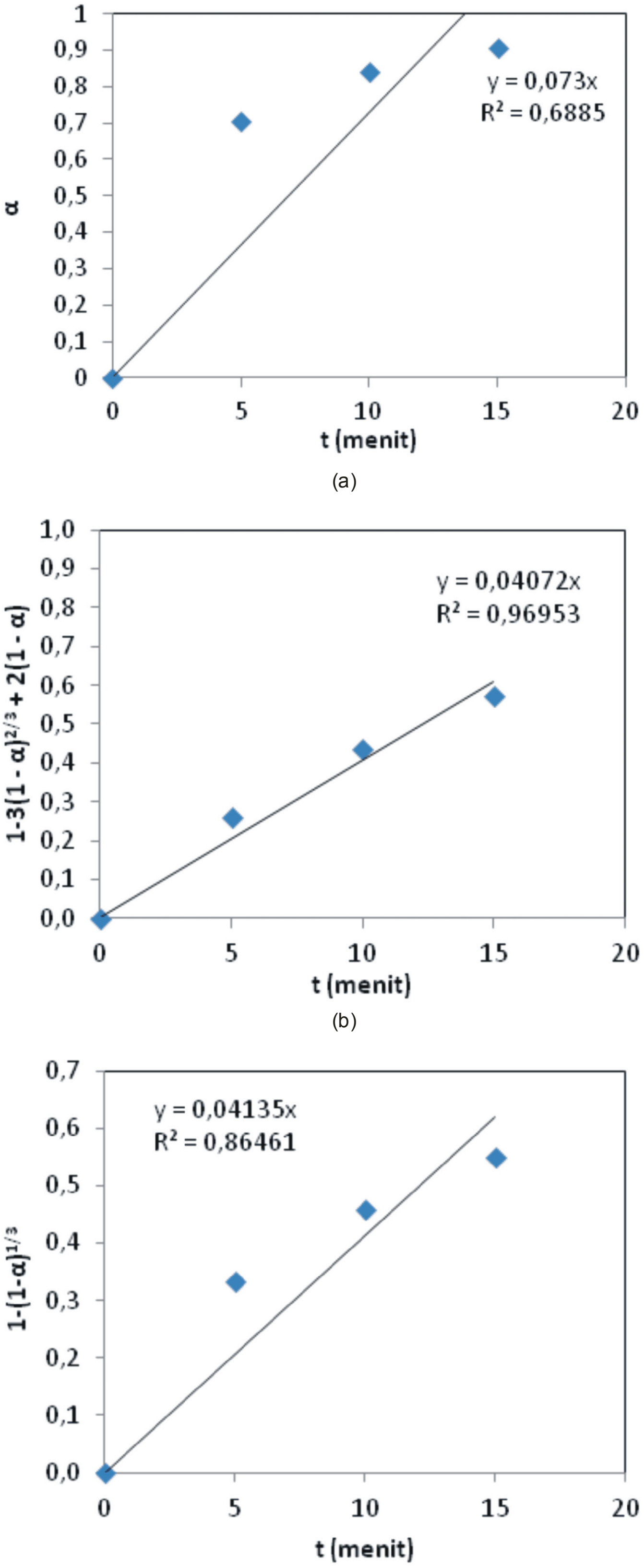


Figure 6. Regression of digestion data at 140°C to the models of kinetics controlled by (a) film diffusion, (b) ash diffusion and (c) chemical reaction

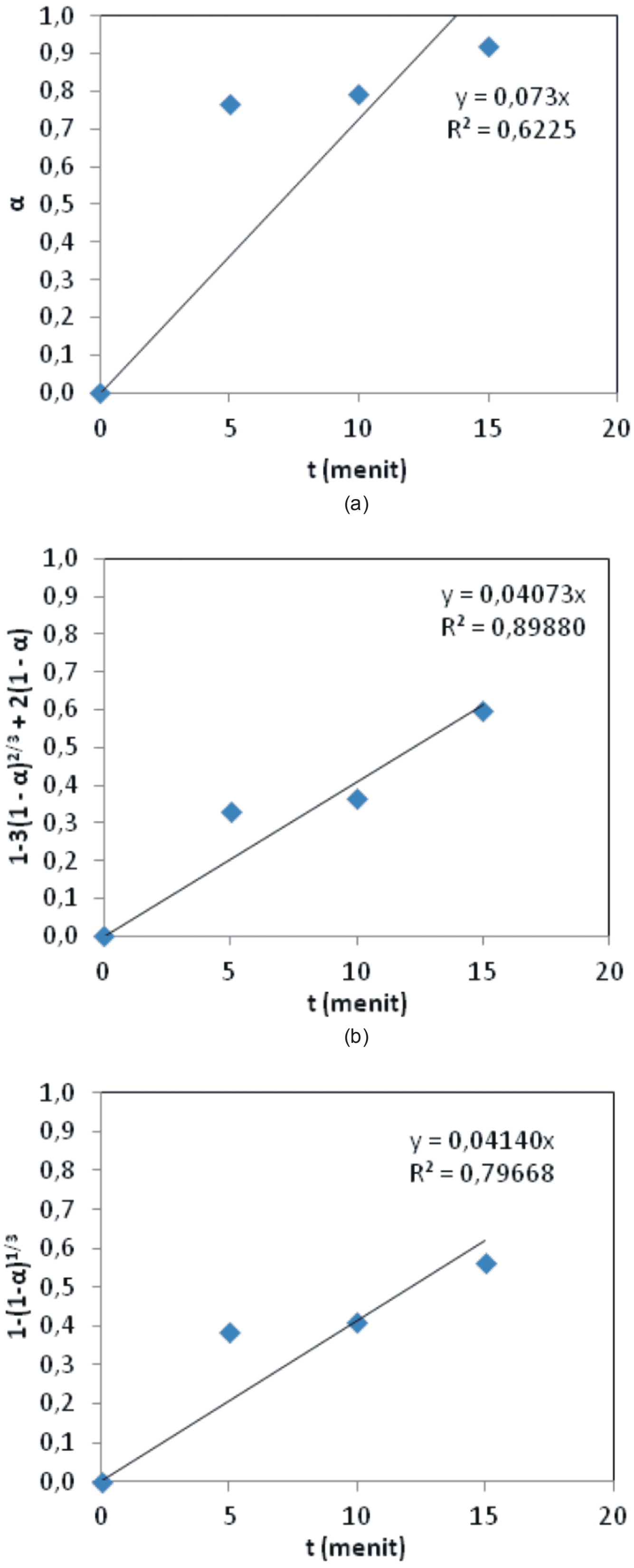


(a)

(b)

(c)

Figure 7. Regression of digestion data at 150°C to the models of kinetics controlled by (a) film diffusion, (b) ash diffusion and (c) chemical reaction



(a)

(b)

(c)

Figure 8. Regression of digestion data at 160°C to the models of kinetics controlled by (a) film diffusion, (b) ash diffusion and (c) chemical reaction

Table 2. The values of τ and R^2 for linier regressions of experimental data for three different temperatures with 3 different kinetic models

Temperature (°C)	Film Diffusion Controlled			Chemical Reaction Controlled			Ash Diffusion Controlled		
	(1/τ)	τ	R^2	(1/τ)	τ	R^2	(1/τ)	τ	R^2
140	0.076	13.158	0.53	0,0463	21.60	1.00	0.0479	20.868	0.75
150	0.073	13.699	0.69	0.0413	24.18	0.86	0.0407	24.558	0.97
160	0.025	13.698	0.62	0.0161	24.155	0.79	0.0169	24.552	0.89

Table 3. The values of De and ln De

1/T	De	lnDe
0.002421	3.74E-19	-42.43
0.002364	4.03E-19	-42.35
0.002309	4.23E-19	-42.31

be minimized to avoid the formation of significant amount of DSP.

Previous kinetics study by Pereira et.al. (2009) was not consider Al precipitation from the reaction of sodium aluminate with sodium silicate in aqueous phase. In order to incorporate the effect of Al precipitation to the kinetic analysis, Bao and Nguyen (2010) had modified the Pereira model into Equation (10). If we substitute the known parameters (i.e. C_{Al} = dissolved Al concentration; $C°_{gibb}$ = initial Al concentration in bauxite and $C°_{gibb}$ = Al concentration in red mud) into Equation (10) then we can obtain the value of k and, thus ln k value. By introducing the respective parameters from the digestion tests at temperatures of 140, 150 and 160°C into Equation (10), the values of k and ln k were determined and summarized in Table 4. Afterwards, plotting and linear regression of ln k versus 1/T was made as shown in Figure 10. From the slope of the profile of ln k versus 1/T, the E_a value of 20.58 kcal/mole was obtained which indicates that the process was controlled by chemical reaction. However, the correlation of ln k and 1/T is not good indicated by the low value of R^2 coefficient. Therefore, another approach of kinetics study was performed by using Equation (9).

By substituting the values of C_{Al}, $C°_{gibb}$ and C_{OH-} into Equation (9), the values of De and ln De for each digestion temperature can be determined. The values of D_e and ln D_e for digestion temperatures of 140, 150 and 160°C and various digestion times are reported in Table 6. Profiles of ln D_e versus 1/T for various time ranges are shown in Figure 11. The profiles of ln De versus 1/T give four straight lines and demonstrates the change of rate determining step by time that is indicated

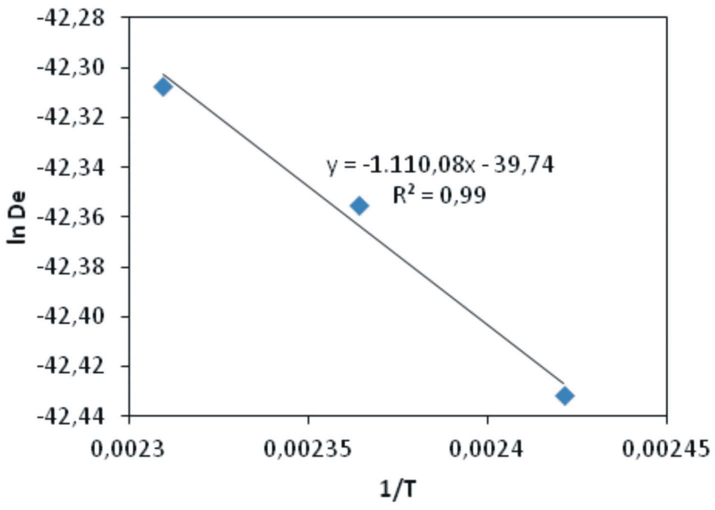


Figure 9. Profile of ln De versus 1/T

Table 4. The values of k and ln k by considering precipitation Al as DSP using Equation (10)

t (minute)	140		150		160	
	k	ln k	k	ln k	k	ln k
15	1.07	0.068	0.71	-0.34	1.10	0.09
30	0.72	-0.32	0.23	-1.45	0.22	-1.52
45	0.34	-1.07	0.17	-1.74	1.022	0.02
60	0.31	-1.16	0.16	-1.82	0.14	-1.95

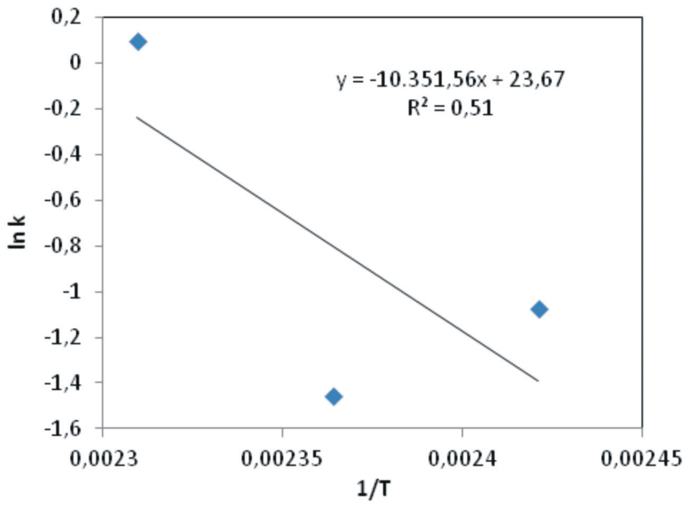


Figure10. Profile of ln k obtained from Equation (10) versus 1/T for the digestion tests at 140, 150 and 160°C

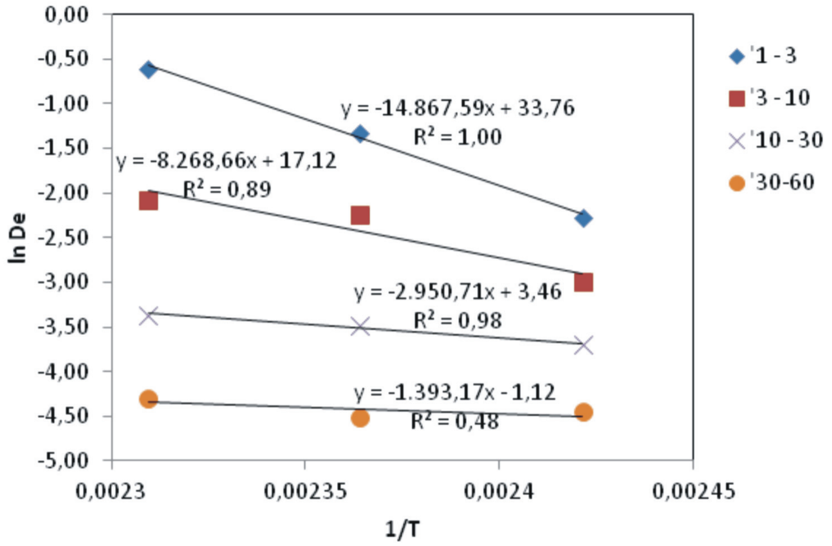


Figure 11. Profiles of ln De versus 1/T for various time ranges

by the change of its E_a values (Table 5). At the beginning of digestion process, Al dissolution is controlled by interface chemical reaction. After certain period of digestion times the rate controlling step changes from chemical reaction to ash layer difussion. This alteration of rate-determining-step is also fit to Aluminum dissolution behaviour as presented in Figure 3, in which Aluminum dissolution increases until certain period of times but the amount of dissolved Aluminum fluctuate due to the formation of DSP. Beyond the time of DSP formation, the kinetics of Aluminum dissolution is controlled by ash layer diffusion. The values of Ea for various digestion times and its relevant rate-determining steps obtained by using Equation (9) are reported in Table 6.

Table 5. Values of De and ln De from digestion tests at 140, 150 and 160oC and various times obtained from Equation 9

t (minute)	140		150		160	
	De	ln De	De	ln De	De	ln De
1			0.39	-0.93	0.55	-0.61
3			0.27	-1.32	0.13	-2.07
5	0.10	-2.27	0.11	-2.24	0.06	-2.82
10	0.05	-2.99	0.05	-2.99	0.03	-3.36
15	0.04	-3.14	0.03	-3.49	0.04	-3.14
30	0.02	-3.69	0.01	-4.20	0.01	-4.29
45	0.01	-4.26	0.01	-4.51	0.02	-3.82
60	0.01	-4.45	0.01	-4.89	0.01	-4.85

Table 6. Values of Ea for various digestion times and its relevant rate-determining step

Time (minute)	Ea/R	Ea (kcal/mol)	Rate control
1 – 3	-14,867.6	29.57	Interface chemical reaction
3 – 10	-8,268.7	16.44	Interface chemical reaction
10 – 30	-2,950.7	5.63	Between Interface chemical reaction and diffusion through ash layer
30 - 60	-1,393.2	2.77	Diffussion through ash layer

CONCLUSION

Dissolved Al concentration increases until a certain period of digestion time in which beyond this time the dissolved Al is fluctuated due to the formation of sodium alumino silicate (DSP) precipitate. The kinetics study of typical West Kalimantan bauxite shows that alumina dissolution is controlled by dissolution through reaction product (ash) layer with activation energy of 2.21 kcal/mole. Kinetics analysis by using a model consider Al precipitation during digestion which demonstrates that there is an alteration of the rate-determining step of chemical reaction (E_a = 29.57 kcal/mole) at the initial period of digestion to diffusion through ash layer (E_a = 2.77 kcal/mole) after the formation of DSP layer. To accelerate reaction kinetics, hence the reactive silica content in ore should be minimized.

ACKNOWLEDGEMENT

Authors would acknowledge the staff of chemical analysts who assist in analysing all samples of raw materials and experimental products, especially to analyze sodium aluminate solution that need special treatment.

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