HYDROMETALLURGICAL PROCESSING
OF EGYPTIAN BAUXITE

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Abstract: A bauxite ore from Um Bogma, Southwestern Sinai, Egypt was mineralogically characterized. It contains 70% gibbsite, 13.2% quartz and 11.0% kaolinite. Beneficiation of the ore reduced the quartz content to 2.4%. Hydrometallurgical processing of the beneficiated gibbsitic bauxite was performed by hot leaching with sodium carbonate and lime in an attritor. Aluminium was converted to soluble sodium aluminate low in SiO_2 (<0.1%) and the recovery was over 95% for a short leaching duration of 30 minutes at 90 °C. The residue was essentially composed of calcium silicate.

Introduction

Bauxite is a chief raw material for aluminum and at present 95% of primary aluminum is produced from this ore. In the last two decades, the discovery of bauxite in Australia, Guinea and Brazil has changed the world bauxite distribution map very significantly. In NE-Africa (Egypt), bauxite laterites are preserved in relictic weathering crusts on the variety of Precambrian basement rocks, as well as on Cretaceous volcanic, and sedimentary type kaolin main periods of lateritic weathering occurred during Early Paleozoic and middle to late Cretaceous times (Andeev et al., 1972).

The Paleozoic and Cretaceous bauxite laterites have in common a complex polystage chemical evolution which comprises either secondary resilication of bauxites or desilication of kaolins. In both cases, the products result in comparably low bauxites or alumina grades. The potential of NE-Africa to supply high-grade bauxites was further reduced due to repeated tectonically induced erosion.

Indigenous non-bauxite materials for alumina production include clays and nepheline syentie, Clays with more than 35% Al_2O_3 are reported to occur in Sinai and Aswan and the estimated reserves are around 35 Tg (million tons). This material is technically suitable for alumina production by sintering as well as acid leaching proc-

esses. Of these, the lime sintering and the nitric acid leaching processes (Scotford and Glastonbory, 1972; Liu et al. 2008) seem to be the most attractive routes. Nepheline syenite with 20% Al_2O_3 and 14% alkali oxides is present in various localities in the Eastern Desert. The estimated reserves is about 25 Tg. These ores are also amenable to processing by lime sintering. However, the alumina production economics have showed that neither of these raw materials would be able to compete with bauxite. This is due to the high investment cost required for their processing which is from 1.5 to 2-fold higher than the conventional Bayer process.

Said et al. (1976) were the first to report the presence of bauxitic material in Egypt in various localities in the Eastern Desert in the weathered crust covering the Nubia complex effusive. Germann et al. (1987) and Fisher et al. (1991) have indicated the possibility of bauxitisation in the southern part of Egypt (south of Kalabsha) and Northern Sudan. Further work was carried out by Segev (1984) on gibbsite mineralization in SW-Sinai.

Among many methods of bauxite processing alkali digestion with NaOH (Cregledi et al., 1981 and Zhao et al. 2010) and acid digestion with HCl have found wider application (Smith, 2009).

The present study deals with mineralogy, beneficiation and hydrometallurgical processing of the Egyptian bauxite deposit. Leaching with sodium carbonate and lime was used in the investigations.

Experimental

Materials and Apparatus

The bauxite sample was obtained from the Um Bogma deposits (Table 1). Pure sodium carbonate and lime were used as leaching and desilication agents, respectively.

Table 1. Chemical analysis of buxite

Component	%
Al_2O_3	50.17
H_2O	27.80
SiO_2	18.22
CaO	1.50
Fe_2O_3	0.32
MnO_2	0.21
MgO	0.12

Leaching experiments were carried out in an attritor – a reactor equipped with high speed stirrer and small balls (Fig.1). The attritor was heated by a thermostatically controlled heating mantle and agitation of the reaction mixture was done mechanically.
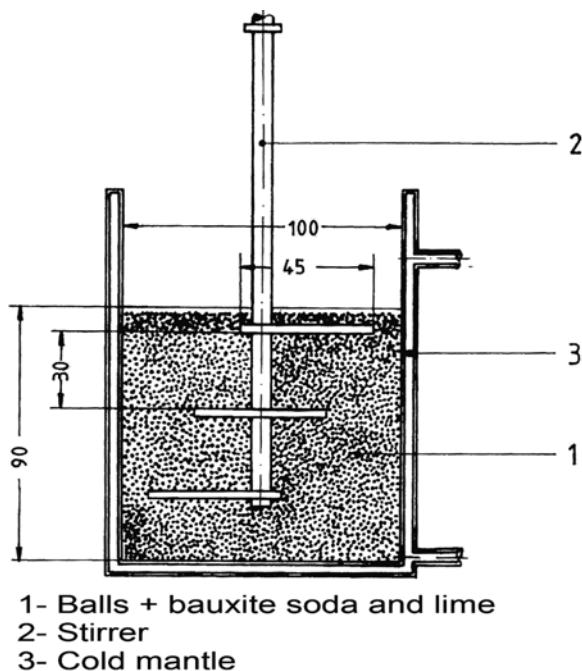
1- Balls + bauxite soda and lime
2- Stirrer
3- Cold mantle

Fig. 1. Sketch of the attritor

Technique of work

Gibbsite and kaolinite were separated from detrital quartz by first pulverizing in a ball mill and then screening through a 63 micron screen. The fines were repulped in water, dispersed thoroughly and then allowed to settle. The suspended fraction was decanted and dried. This fraction contained only 2.4% quartz indicating removal of about 82% quartz.

Calculated amounts of sodium carbonate solution and lime were added in the attritor and heated up. The amount of lime was adjusted to be in stoichiometric proportion to the silica present in the bauxite. On attaining the required temperature calculated amount of bauxite was added under agitation. Samples were withdrawn periodically for analysis of aluminum and silicon in the leach liquor.

Results and discussion

Mineralogy

X-Ray diffraction study

X-ray diffraction analysis of the bauxite sample (Fig. 2) revealed the presence of gibbsite ($Al_2O_3 \cdot 3H_2O$), kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and goethite ($FeO \cdot OH$).
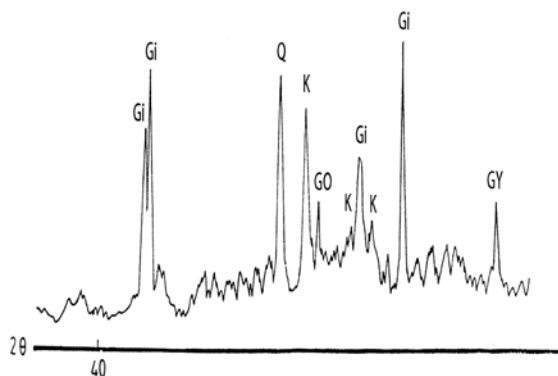
Fig. 2. X-ray diffraction pattern of Um Bogma bauxite
sample using filtered Co Ka radiation.
Gi: gibbsite, Q: quartz, K: Kaolinite, Go: Geothite

Diffraction thermal analysis

From the differential thermal analysis of the bauxite sample (Fig. 3) the following
observations are made.

(i)   A small endothermic peak occurs at about 90 ºC due to the loss of surface ad-
      sorbed water.

(ii) A large endothermic peak is formed at a temperature of about 320 ºC due to the
      loss of interlayer OH of water which is associated with a significant weight loss
      of about 17.6 to 21.1% with an average of 19.35%. This peak is characteristic of
      gibbsite mineral (Belyaev et al., 1964; Cregledi et al., 1981; Kuznetsova et al.,
      1964).

(iii) A small endothermic peak is seen at a temperature of 550 ºC due to dehydration
      of kaolinite. The temperature is influenced by the degree of crystallinity of kao-
      linitic material.

(iv) The re-occurrence, of an endothermic DTA peak at about 950 ºC is seen as the
      structural peak attributable to the formation of gamma-alumina and tridymite. The
      complete mineralogical analysis of the bauxite sample is given in Table 2.

Table 2. Mineralogical analysis of studied bauxite sample

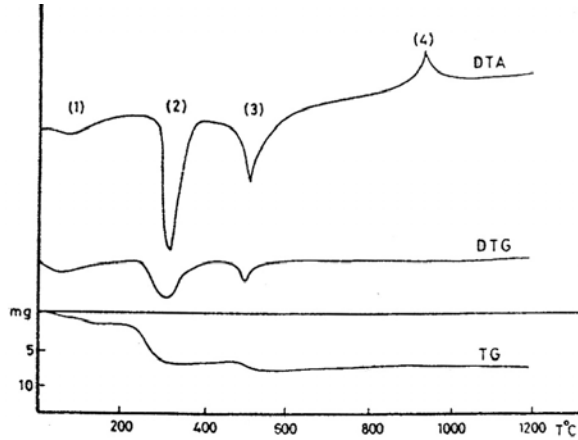| Mineral	capacity, %
Gibbsite, $Al_2O_3 \cdot 3H_2O$	70.1
Quartz, SiO_2	13.2
Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	11.0
Gypsum, $CaSO_4 \cdot 2H_2O$	3.1
Geothite, $FeO \cdot OH$	1.5

Fig. 3. Derivatogram of representative bauxite sample

Hydrometallurgical processing

The main parameters affecting the efficiency of the leaching process were systematically studied.

Effect of temperature and time

Figure 4 shows the effect of temperature (50–90 °C) and time (30–120 min) on the leaching behavior of gibbsitic bauxite. The experiments were carried out using 0.3 M sodium carbonate solution and lime to correspond to CaO/SiO_2 ratio of 2.0 at solid content around 30%. Aluminum recovery increases with increasing temperature from 50 °C MP to 90 °C and time. The optimum Al recovery was >95% for leaching condition of 90 °C and 30 min.

Further increase in the leaching time to 40 min had no significant effect on the Al recovery.
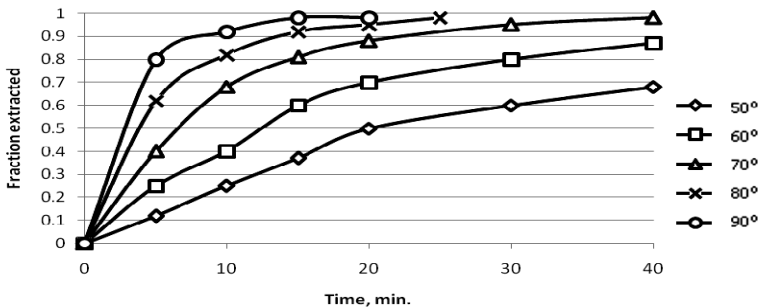

Fig. 4. Effect of temperature on the extraction of aluminum

Effect of sodium carbonate concentration

Figure 5 shows effect of sodium carbonate concentration (0.1–0.9 M) on the Al recovery. Leaching was done under the optimized conditions. It is seen that Al recovery increases with increasing sodium carbonate concentration up to 0.3 M. Further increase in the carbonate concentration did not improve the recovery.
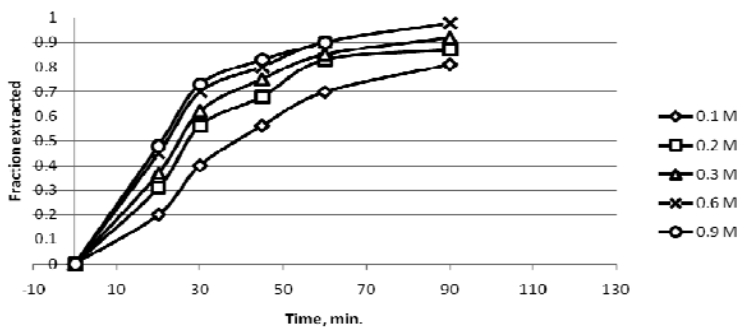

Fig. 5. Effect of sodium hydroxide concentration on the extraction of aluminum

Effect of CaO/SiO$_2$ mole ratio

Figure 6 shows the effect of CaO/SiO$_2$ mole ratio under the optimum leaching conditions. It is noticed that there is a direct proportionality between the aluminum recovery and the CaO/SiO$_2$ ratio in the mole ratio range of 0.5 to 2.0. The optimum Al recovery achieved was 92% at the CaO/SiO$_2$ ratio of 2.0. An increase in the CaO/SiO$_2$ ratio beyond 2.0 led to a significant decrease in the Al recovery, essentially due to the formation of sodium calcium aluminum silicate by the reaction of calcium silicate and sodium aluminate.
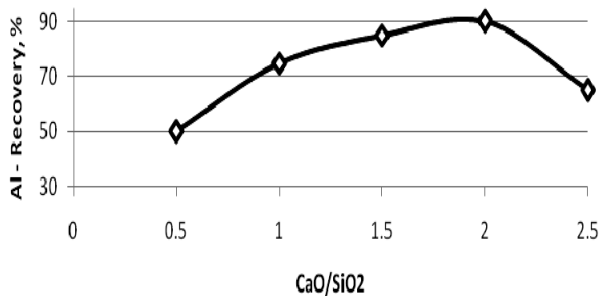

Fig. 6. Effect of ratio of CaO/SiO$_2$ on Al recovery

Table 3. Chemical analysis of leach liquor

Component	%
Al_2O_3	10.010
Na_2O	11.190
SiO_2	0.096
Caustic molar ratio*	1.839
Alumina/Caustic ratio, A/C**	0.520
Density. g/ml	1.269

* Caustic ratio = (Na_2O, g/dm^3 X 102) / (Al_2O_3, g/dm^3 X 62)
** A/C = (Al_2O_3, g/dm^3) (Na_2O, g/dm^3), (Na_2O expressed as Na_2CO_3)

Desilication

The sodium aluminate leach liquor analyzed less than 0.1% silica (Table 3). This is due to the very low reaction rate of silica with sodium carbonate at the leaching temperature (90 °C) 12. Thus, there is no need for a desilication step in the further processing of the leach liquor to produce alumina.

Kinetic aspect

The chemical reactions of gibbsite with sodium carbonate and lime are given bellows:

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3 \tag{1}$$

$$Al_2O_3 \cdot 3H_2O + 2NaOH \rightarrow 2NaAlO_2 + 4H_2O. \tag{2}$$
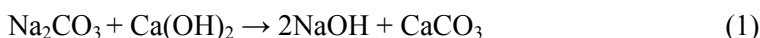
Silica reacts with sodium hydroxide to from sodium silicate, which then reacts with calcium carbonate to form calcium silicate:

$$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O \tag{3}$$

$$Na_2SiO_3 + CaCO_3 \rightarrow CaSiO_3 + Na_2CO_3. \tag{4}$$

The leaching rate does not increase linearly with the concentration of sodium carbonate above 0.3 M. The rate seems to be limited by the concentration of hydroxide adsorbed on the surface of bauxite. If bauxite reacts with hydroxides already adsorbed on the surface of the bauxite, then the rate of reaction at the surface of sphere of radius *r* may be expressed as:

$$\frac{dn}{dt} = 4\pi r^2 k C_{Na_2CO_3} \tag{3}$$

where *n* is the number of bauxite moles in the particle at time *t*, *k* is the surface reacting rate constant (taking into account the shape factor and surface roughness), *r* is the radius of the unreacted core of the particle and $C_{Na_2CO_3}$ is the concentration of hydroxides adsorbed on the surface of the bauxite (mole/unit area).

First-order dependence on $C_{Na_2CO_3}$ was assumed in Eq. (3). The adsorption of hydroxide takes place faster than the leaching rate and the concentration of $C_{Na_2CO_3}$ is much higher than stoichiometry required. Eq. (3) can be integrated to give

$$1 - (1 - \alpha)\,1/3 = Kt \tag{4}$$

where α is the extent of extraction of aluminum, and t is the leaching time. The dependence of grinding time in attritor is illustrated in Fig. 7. The empirical rate constant is compared with the specific surface area of the ground sample in Fig. 8. It is concluded that the rate is a linear function of specific surface area in the interval 1.0–3 m^2/g. Such dependence is quite consistent with the leaching theory. It is also concluded that there is practically no dependence of the rate constant on surface area higher than 3 m^2/g. The formation of agglomerates, as a consequence of grinding may be the reason.
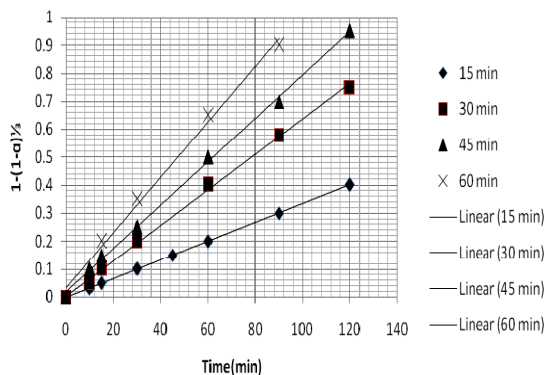

Fig. 7. Linear plots according to the surface reaction model for the effect
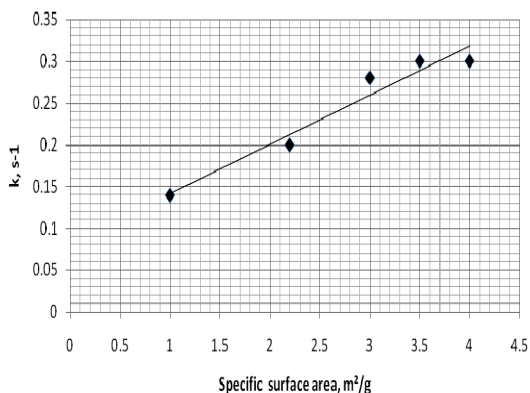of grinding time in attritor on leaching rate

Fig. 8. Dependence of reaction rate (k) on specific surface area of ground bauxite

The surface reaction model was applied to determine the activation energy. The date are presented in Fig. 9. The apparent rate constants were determined from the straight lines of Fig. 9. and plotted according to the Arrhenius equation as shown in Fig. 10.
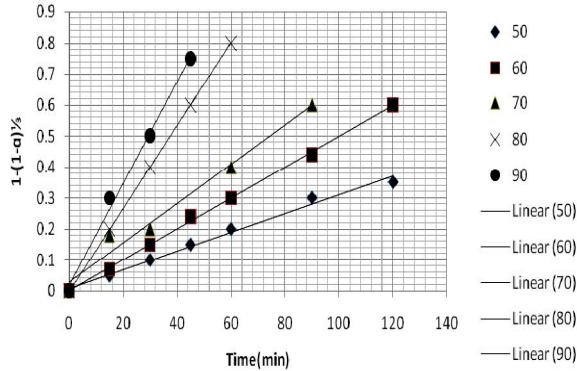

Fig. 9. Linear plots according to the surface reaction model for the effect of temperature on leaching rate. Data are given from Fig.4
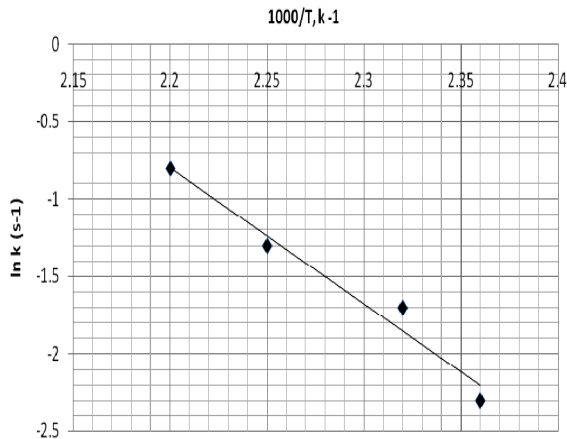

Fig. 10. Arrhenius plot of the apparent rate constants

The activation energy was determined to be 34 kJ/mole and the magnitude of this value confirms the proposed surface reaction control mechanism (Habashi, 1989 and Amer, 1996). The data of Fig. 5, which represents the effect of sodium carbonate concentration on Al recovery, plotted according to Eq. (4), give a linear relationships shown in Fig. 11. The slopes of the straight lines represent the apparent rate constant which are plotted as a function of sodium carbonate concentration in Fig. 12. The apparent rate constant increase and then levels off as the concentration of sodium hydroxide increases. This means that the apparent reaction order with respect to sodium

hydroxide concentration varies from first to zero as the concentration of sodium carbonate increases.
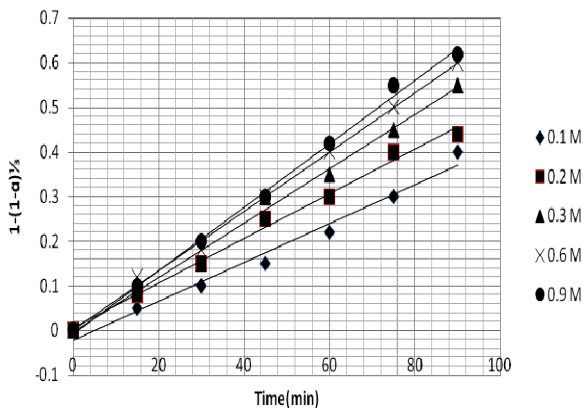

Fig. 11. Linear plots according to the surface reaction model for the effect of NaCO$_3$ concentration on leaching rate. Data from Fig.6
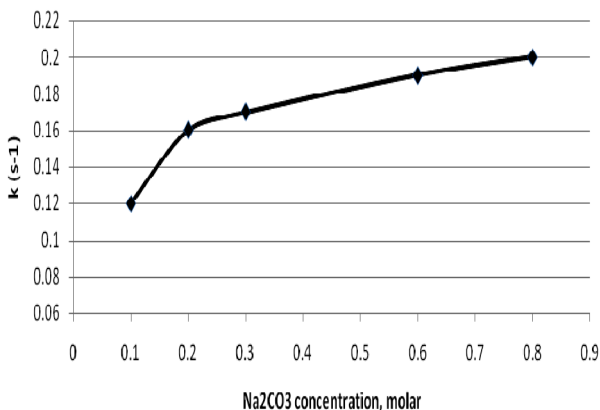

Fig. 12. Variation of the apparent rate constant (k) with Na$_2$CO$_3$ concentration

Conclusions

The bauxite ore from Um Bogma, Southwestern Sinai consists mainly of gibbsite (70.1%) and kaolinite (11.0%). Beneficiation of the ore has brought down the silica content from 13.2 to 2.4%. Hydrometallurgical processing of the beneficiated bauxite in an attritor has given a high Al recovery of 95% for a short leaching duration of 30 min at 90 ºC. The sodium aluminate leach liquor obtained under the above conditions contains less than 0.1% silica. There is no need for a desilication step in the conversion of the leach liquor to alumina. It can also be concluded that there is practically no

dependence of the rate constant an surface area higher than 3 m^2/g. The activation energy was determined to be 34 KJ/mol and its magnitude confirms the proposed surface reaction control mechanism.

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