Technological Investigations of the Kibi Bauxite: Digestion

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ABSTRACT

Digestion conditions of the bauxite were studied using four different samples from the Kibi deposit. The samples were digested at 140°C and 240°C employing liquor concentrations between 140 and 200 $kg.m^{-3}$ as sodium oxide. Results indicated that the digestion efficiency was low (61-77%) for digestion at 140°C. This was probably due to the insolubility of substantial amounts of boehmite present in some of the bauxite samples and, to some degree, to the gibbsite-boehmite transformations under these conditions. Digestion efficiency at 240°C was high (above 80%), especially for liquor concentrations of 160$kg.m^{-3}$ and above, because of the dissolution of boehmite.

Energy analysis of the various digestion conditions showed that percentage primary heating energy for the high temperature digestion was low, but in absolute terms higher than for low temperature digestion. Settling tests indicated that because the rather coarse dispersions of the boehmite and geothite phases remained unchanged at 140°C, settling properties of the bauxite residue were better than for digestion at 240°C.

KEY WORDS: digestion efficiency, energy consumption, settling characteristics.

INTRODUCTION

Even though attempts had been made to find other potential ores to replace bauxite, this ore still remains the main raw materials for aluminium production. The Bayer Process contributes about 95% of the alumina needed to feed reduction plants because of the higher energy requirements of other technologies [1], and the choice of this technology depends entirely on the type and quality of the bauxite ore.

A major portion of the energy consumed in a Bayer plant is used in the digestion units [2,3,4]. It is estimated that digestion systems use about 40% of total energy used in alumina plants [5]. This energy is mainly used as heating energy (primary steam) and as motive energy (to circulate process liquor). The digestion units therefore constitute an area of possible energy savings in an alumina plant. The analysis of the energy requirements of digestion variants is therefore necessary in the choice of process technology, taking into account the energy supply conditions of the country.

In this paper the digestion conditions of the Kibi bauxite were studied using different samples and the energy requirements for the digestion condition were estimated. The effect of digestion conditions on the settling characteristics of the digestion residue was also studied.

EXPERIMENTAL

Four samples, (Samples 1, 2, 3 and 4) of varying chemical and mineralogical compositions from the Kibi deposit (Tables 1 and 2) were prepared and digested in steel bombs rotated in an oil bath. The digestion time was one hour. Each sample was digested at 140°C and 240°C using a liquor of caustic sodium oxide of concentration 140 $kg.m^{-3}$.

TABLE 1 CHEMICAL COMPOSITION OF THE BAUXITE SAMPLES

COMPONENT	SAMPLE 1 %	SAMPLE 2 %	SAMPLE 3 %	SAMPLE 4 %
Al_2O_3	45.6	53.7	46.0	56.5
SiO_2	4.5	4.8	5.2	1.0
Fe_2O_3	22.1	43.8	18.3	8.4
TiO_2	3.7	4.0	2.8	4.1

TABLE 2 MINERALOGICAL COMPOSITIONS OF THE BAUXITE SAMPLES

PHASE	SAMPLE 1 %	SAMPLE 2 %	SAMPLE 3 %	SAMPLE 4 %
Al_2O_3 in gibbsite	31.9	40.0	36.1	42.0
boehmite	8.4	9.8	4.8	12.5
kaolinite	2.8	1.4	3.4	0.9
goethite	7.0	1.8	1.5	0.8
hematite	0.2	0.2	0.2	0.1
Fe_2O_3 in goethite	11.2	9.9	9.7	5.5
hematite	10.9	3.9	8.6	2.9

In addition, sample 1 was also digested using liquor of concentration 160, 180 and 200 $kg.m^{-3}$. After digestion, the liquor and solid phases were separated in a centrifuge. The liquor phase was analysed for caustic sodium oxide and aluminium oxide content, whilst the mineralogical composition of the digestion residue was also determined using X-ray diffraction, Infrared spectrophotometric and Differential Thermogravimetric and Thermal Analytical methods. In the chemical analysis of both bauxite and digestion residues the samples were first dissolved in a mixture of hydrochloric, nitric and sulfuric acids. The total silica content was determined gravimetrically and the total iron oxide oxidemetrically, whilst the alumina content was determined complexometrically.

For the settling tests, sample 4 was digested at 140 and 240°C using liquor of concentration of 140 $kg.m^{-3}$. The slurry was diluted to a solid concentration of 100 $kg.m^{-3}$ and tests run in a settling tube thermostatically controlled at 95°C. As a settling aid, industrial flour was added to the slurry in amount of 2 kilograms per tonne dry mud. The mud level was recorded as a function of time.

RESULTS AND DISCUSSIONS

Digestion Conditions

The extraction efficiency at the various digestion conditions were determined [7]:

$$= [1- \frac{Al_2O_{3m}\ Fe_2O_{3bx}}{Al_2O_{3bx}\ Fe_2O_{3m}}] \times 100 \qquad 1$$

where Al_2O_{3m} is the percentage alumina content of the digestion residue.

Al_2O_{3bx} is the percentage alumina content of the bauxite

Fe_2O_{3m} is the percentage iron oxide content of the digestion residue.

Fe_2O_{3bx} is the percentage iron oxide content of bauxite.

The effect of temperature on digestion of sample 1 is shown in Fig.1, whilst the effect of liquor concentration is presented in Fig.2. The characteristic curves for samples 2, 3 and 4 at 140 and 240°C digestion temperatures are shown in figures 3 and 4.

The results indicated that the overall extraction efficiencies for all samples were higher at 240°C digestion temperature, varying between 81.5 and 91.0%.

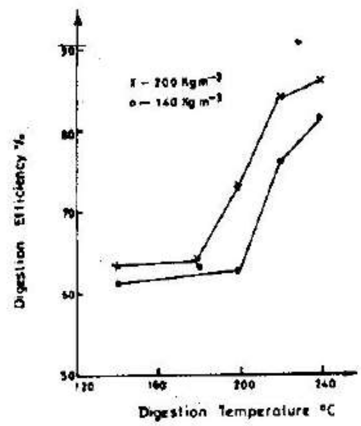

Fig.1. Effect of Temperature on the Digestion of Sample No.1.

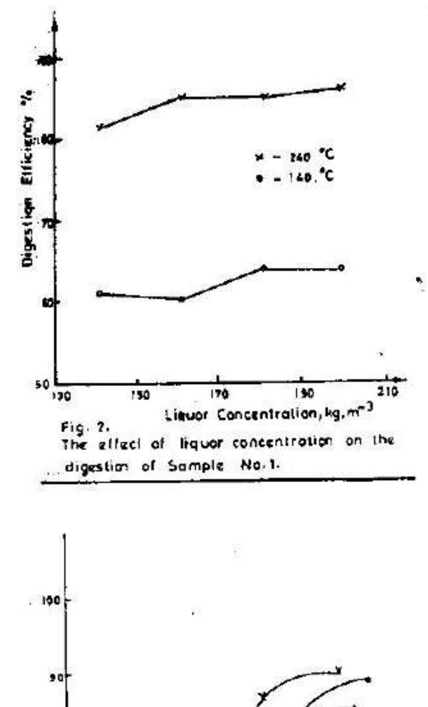

Fig. 2.
The effect of liquor concentration on the digestion of Sample No.1.

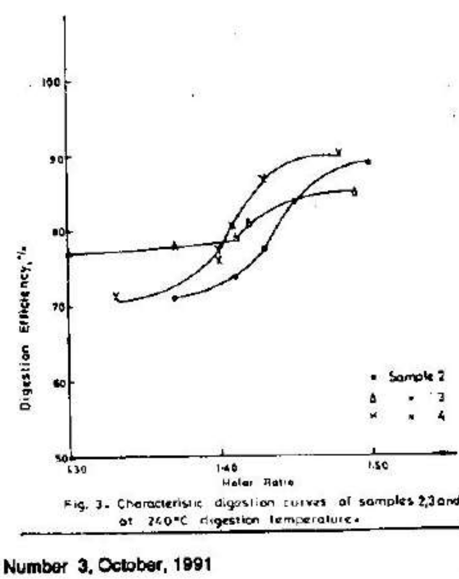

Fig. 3. Characteristic digestion curves of samples 2,3 and 4 at 240°C digestion temperature.

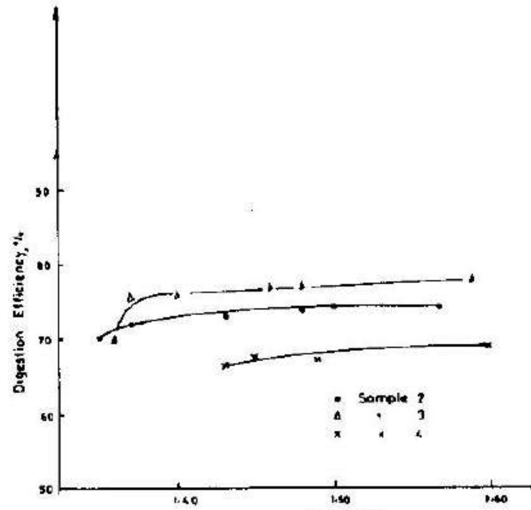

Fig.4. Characteristic digestion curves of samples 2, 3 and 4 at 140°C digestion temperature

For digestion at 140°C the efficiencies were low (between 61.3 and 77.4%). At this temperature the boehmite content of the bauxite remained undissolved, as confirmed by phase analysis of the bauxite residues (Table 3 and 4). There was also evidence of phase transformation of gibbsite to boehmite, especially for samples 1, 2 and 4, whose boehmite contents were more than 5% in the bauxite. This transformation at 140°C is probably triggered by the presence of large amounts of boehmite, which acted as seeds. As a result of the lower solubility of boehmite the extraction efficiency at this temperature was low.

TABLE 3 PHASE COMPOSITION OF RED MUDS OF SAMPLE 1 AT VARIOUS DIGESTION CONDITIONS

Digestion Temp. °C	140		240			
Digestion Liquor Concentration, kg/m^3	140	200	140	160	180	200
Al_2O_3 % in goethite	2.7	2.1	2.0	3.1	2.7	3.6
hematite	0.6	0.6	0.5	0.6	0.6	0.5
boehmite	19.0	22.1	7.9	1.3	2.2	0.5
Fe2O3 % in goethite	19.7	15.6	19.9	19.2	10.2	20.2
hematite	21.3	25.2	29.7	31.1	31.2	30.4

TABLE 4 PHASE COMPOSITIONS OF RED MUDS FOR SAMPLES 2, 3 AND 4 AT VARIOUS DIGESTION CONDITIONS

SAMPLE	SAMPLE 2		SAMPLE 3		SAMPLE 4	
Dig. Temp., °C	140	240	140	240	140	240
Dig.Liq.Conc.,kg/m^3	140	140	140	140	140	140
Al_2O_3 % in gouthite	3.7	3.4	3.0	2.7	2.4	2.8
hematite	0.5	0.6	0.5	0.1	0.3	0.5
boehmite	23.9	4.8	11.1	1.6	43.2	16.7
Fe_2O_3 % in goethite	20.7	24.7	21.7	19.5	13.8	19.6
hematite	14.9	17.1	22.6	28.1	10.9	19.5

The effect of liquor concentration was not pronounced. However for digestion at 240°C it was realised that a minimum concentration of 160 $kg.m^{-3}$ was necessary for more efficient extraction.

Digestion Energy Analysis

The main energy input into digestion is the primary steam. In up to date technologies secondary steam is recovered from high-temperature pregnant liquor in a series of flash tanks and is used in heating up in-coming slurry into the digestion system, among others. As a result, only the last digester tank is heated with primary steam. This constitutes a lot of energy savings.

In order to determine the amount of secondary or recovered steam (R), as well as the primary heating steam (S), heat balances were set up separately for the flash and for the digestion system as a whole (Fig.5 and 6). For simplicity the heat capacities of the slurry before (Cp_f) and after the flash tanks (C_{po}) were assumed equal, the heat losses through the wall (Qw) and by waste steam (W) were neglected. The heat of reaction (Qr) was calculated from the heat of dissolution of gibbsite and boehmite [9] and the gibbsite and boehmite contents of the bauxite. The recovered steam was calculated as follows:

$$R = \frac{GC_{po}(t_1 - t_o)}{i_r - C_{po}t_o} \qquad 2$$

Plant process data was used in the energy analysis. The concentration and molar ratio (d) of diluted liquor going to precipitation was 150 $kg.m^{-3}$ and 1.50. The estimated values of the recovered and primary steams were determined according to the heat balance. Other process parameters were also calculated. These data (for sample 1) were summarised in Tables 5 and 6.

The results indicated that even though no appreciable increases were obtained in digestion efficiency for increases in the concentration of digestion liquor, the volume of digestion liquor and (through this, the motive energy demand) decreased. The amounts of primary and recovered steam also decreased. The percentage energy recovered after digestion at 140°C was 40-43% of total digestion energy, whilst at 240°C this value was 57-59%. The primary energy demand for digestion at 140°C was between 3.1-3.8 $GJ.t^{-1}$ alumina. At 240°C the energy demand was between 4.4 and 5.3GJ.

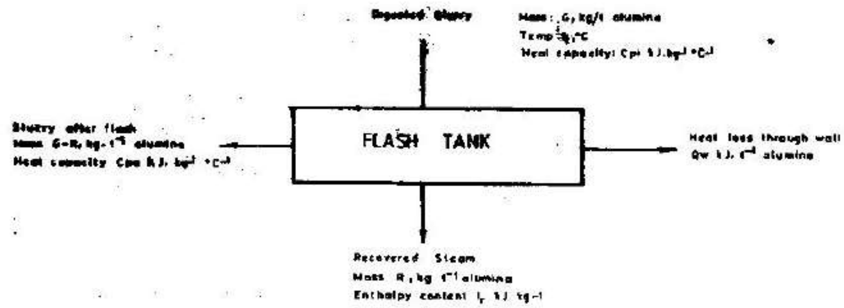

Figure 5: The heat balance of the flash tank

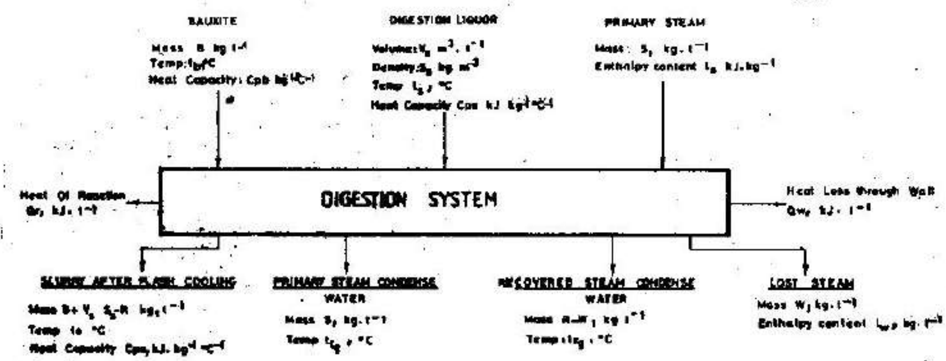

Figure 6: The heat balance of the digestion system

TABLE 5: ESTIMATED PROCESS DATA PER TONNE OF ALUMINA FOR DIGESTION AT 140°C

Liquor Concentration, kg/m^3	140	200
Volume of digestion liquor, m^3/t	11.3	8.0
Volume of diluted liquor, m^3/t	11.9	11.9
Bauxite consumption, t/t	3.542	3.414
Amount of red mud produced, t/t	1.962	1.822
Recovered steam, t/t	1.063	0.781
Fresh Heat steam, t/t	1.329	1.093
Percentage energy recovered, %	43	40
Efficiency of Bayer cycle, $kg\ Al_2O_3/m^3$	89	124
Efficiency of digestion %	61.3	63.6

TABLE 6: ESTIMATED PROCESS DATA PER TONNE ALUMINA FOR DIGESTION ATR 240°C

Liquor Concentration, kg/m^3	140	160	180	200
Volume of digestion liquor, m^3/t	12.7	11.2	10.0	9.0
Volume of diluted liquor, m^3/t	13.4	13.4	13.6	13.3
Bauxite consumption, t/t	2.664	2.551		2.524
Amount of red mud produced t/t	1.237	1.123	1.128	1.125
Recovered Steam, t/t	2.347	2.196	1.984	1.812
Fresh Heat Steam, t/t	1.679	1.661	1.506	1.407
Percentage energy recovered, %	59	58	58	57
Efficiency of Bayer cycle, $kg\ AL_2O_3/m^3$	88	100	112	124
Efficiency of digestion, %	81.5	85.1	84.4	86

The specific bauxite consumption and the amount of red mud (source of environmental pollution!) produced were much higher for digestions at 140°C, than those at 240°C.

Settling Properties of Digestion Residue

The results of the settling tests, as shown in Fig.7, indicated that the settling characteristics of the digestion residue obtained at 140°C, were better than those at 240°C. At 140°C the relatively well crystallised boehmite phase, as well as the iron

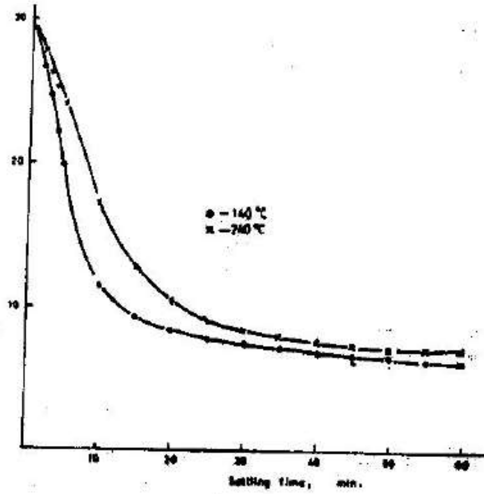

Fig 7 Settling Characteristic Of Digestion Residue

minerals which occur as coarse dispersions in the bauxite [6] remained undissolved or unchanged. As a result the settling rate was good.

At 240°C there was a disintegration and greater solubility of the boehmite crystals, and at the same time there was a dehydration and partial disintegration of goethite into finely dispersed hematite. As a result the particles of the digestion residue became finer than as obtained at 140°C. Therefore the settling rate was poorer, even though the compression properties were similar.

CONCLUSION

Results showed that the digestion efficiencies at 140°C were low, between 61-77%. This was attributed to the indigestibility of the boehmite content of the bauxite, which was high in some samples. There was also some gibbsite-boehmite phase transformation under these conditions. At 240°C digestion temperature the boehmite content of the bauxite became soluble leading to an increase in digestion efficiency (above 80%) especially for liquor concentration of 160 $kg.m^{-3}$ and above.

Energy analysis of the various digestion conditions showed that the percentage primary heating energy was lower for digestion at 240°C, but in absolute terms higher than at 140°C. The primary energy demands were 4.4-5.3 $GJ.t^{-1}$ and 3.1-3.3 $GJ.t^{-1}$ alumina respectively. The recovered energy after digestion at 240°C and 140°C were 57-59% and 40-43% respectively. Settling tests indicated that better settling properties were exhibited by residues obtained at 140°C, than those at 240°C. This was attributed to the disintegration and solubility of the coarse boehmite particles, the dehydration and transformation of some goethite into finely dispersed hematite particles at 240°C.

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