

Energy Consumption Optimization in Alumina Production

Bekir Çelikel¹, Hüseyin Arıkan² and Sema Vural³

1. Alumina Process Engineer

ETI Aluminium Inc., Seydişehir/Konya, Turkey

2. Professor,

3. Assistant Professor

Necmettin Erbakan University, Faculty of Engineering, Mechanical Engineering Department,
Konya, Turkey

Corresponding author: bekir.celikel@etialuminyum.com

Abstract

The alumina production process consumes not only raw materials, but also different forms of energy such as electrical, natural gas and steam. Energy is a key component of production cost, and the alumina industry works toward energy consumption reduction to maintain or improve their place in the world market. Energy is primarily used in the Bayer process as steam in the digestion and evaporation areas. The ETI alumina refinery in Seydişehir has been examining ways to reduce energy consumption and improve the overall energy efficiency of the refinery. This has included evaluating process design parameters, equipment efficiency, and waste heat recovery. In this paper, an understanding the overall refinery energy usage is first established, then the operating efficiency in terms of energy consumption is evaluated by examining the major energy consuming areas of digestion and evaporation. The study has shown that the energy efficiency of the ETI alumina plant can be improved in the digestion area by lowering the molar ratio and in the evaporation area by by-passing spent liquor around the evaporation circuit.

Keywords: Bayer Process; Energy Optimization; Evaporation; Digestion; Steam

1. Introduction

The Eti Alumina plant is located in the south of Turkey, and has been processing bauxite mined from the Seydişehir deposit in the Konya Province since 1973. To maintain its profitability, all consumptions by the refining process must be critically checked, calculated and controlled.

The Bayer process for alumina production is a highly energy intensive in practice. The cost borne by refiners in meeting this energy requirement represents a significant percentage of the unit cost of producing a tonne of alumina. Energy use in the alumina refining process is usually in the form of fossil fuels such as diesel, gasoline, natural gas and coal, or as electricity. The theoretical energy consumption for alumina production is thermodynamically calculated for all the reactions in the process to determine the lowest possible energy consumption for alumina production. Thermodynamically, the variation in the theoretical energy consumption for producing alumina from diaspore, boehmite and gibbsite primarily relies on the key reactions and their conditions; temperatures and concentrations etc. Figure 1 illustrates that the heat of dissolution for all sorts of alumina minerals in caustic liquor is small compared to the total energy consumption in alumina production. This gap widens for monohydrate bauxites, when the dissolution temperature steps up, often to more than 250 °C

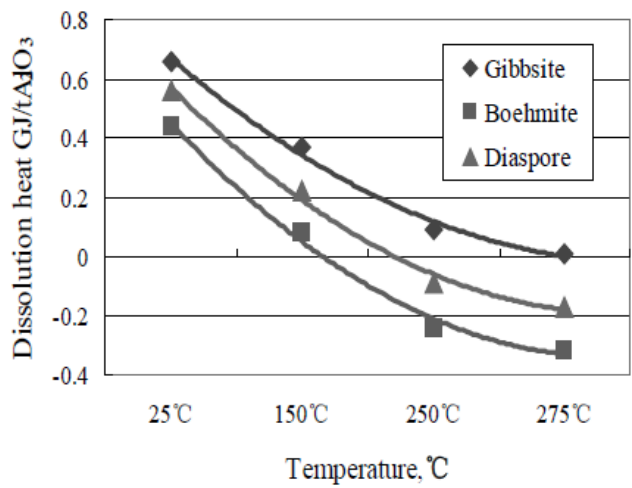


Figure 1. Dissolution heat for different alumina minerals in caustic solution

The literature suggests that theoretical energy consumption in chemical reactions is less than 1 GJ in the Bayer process. Energy used for hydrate calcination to alumina is about 1.4 GJ per ton of alumina and 70% of total theoretical consumption in chemical reactions. Heat transfer processes incur losses which increase the lowest achievable energy consumption beyond this theoretical value. However, real energy consumption in the Eti Alumina refinery is much higher and about 6-7 times this theoretical energy consumption estimated above. Detailed analysis of the energy consumption by all the stages of Bayer cycle and calcination discloses that most of this extra energy is used in efficiency losses in processes and equipment.

The real energy consumption for alumina production involves not only the heat of reaction in digestion, precipitation and hydrate calcination, but also the energy used in range of the physical processes in all the stages of the Bayer process, e.g. preheating for temperature elevation of slurry, evaporation for raising liquor concentration and heat loss from pipes & vessels. It is obviously valuable to reduce the energy consumption for operational cost cutting in alumina production, particularly for the high energy consumption processes and where energy costs are high.

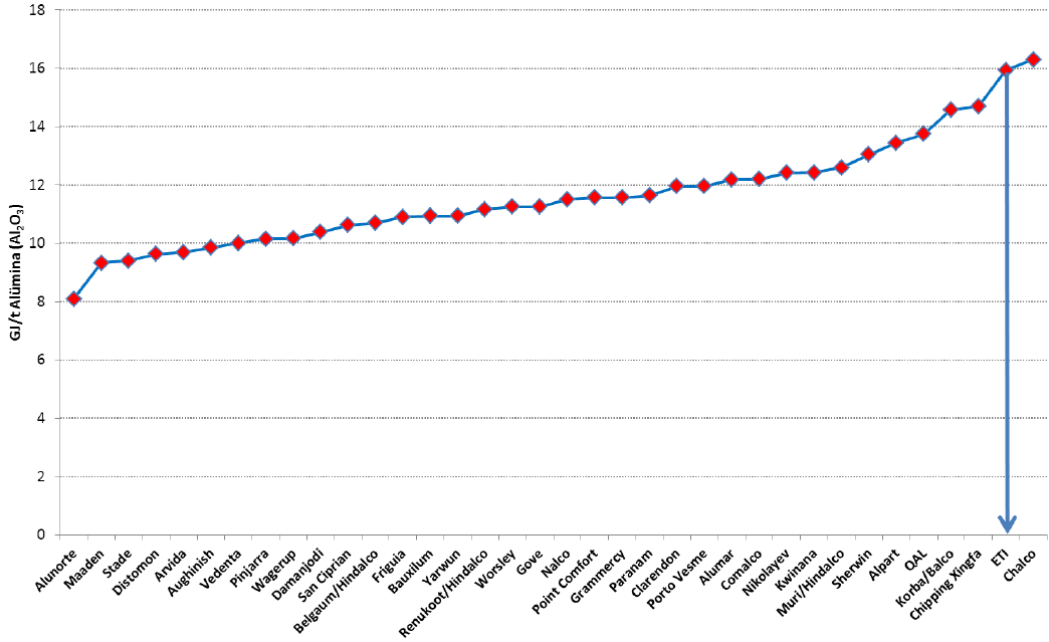


Figure 2. Energy consumption of some refineries over worldwide

The energy demanded to produce alumina from bauxite has been reported to extend from below 8 GJ/t to 16.5 GJ/t and above of alumina. This wide range of energy intensity reflects both bauxite quality (alumina content) and refinery design.

In the Eti Alumina refinery, energy is major cost element at 47 % of the total production cost. To produce 1 ton of calcined alumina, 16 GJ energy has been consumed in digestion and in evaporation as steam and in calcination as natural gas. An investigation has been undertaken on process energy consumption examining the impact of liquor concentration variations by dilution and evaporation, temperature changes up and down by heat exchangers and flash tanks and water balance in the process. An approach of systematic energy recovery is introduced based on a systematic energy analysis of the Bayer cycle. Process stages such as calcination, evaporation and digestion can be classified as the most highly energy consuming processes in alumina production and it is of importance to improve the energy efficiency in these process stages.

2. Energy Saving Opportunities

2.1. Digestion

Bauxite quality, in particular the content of available alumina, reactive silica and organic carbon significantly affect the performance of an alumina refinery. The Eti Alumina refinery processes low quality boehmitic bauxites from Mortaş and Doğankuzu. Table 1 shows the average chemical analysis of these bauxites.

Table 1. Eti Alumina Plant Bauxite Characterization.

| Comp. | Moist. | TAA | LOI | SiO2 | Fe2O3 | Al2O3 | TiO2 | CaO | CO2 | P2O5 | V2O5 | K2O | Ga2O3 | SO3 |
|-------|--------|------|------|------|-------|-------|------|------|-------|-------|-------|-------|--------|-------|
| %,w/w | 2,82 | 50,5 | 12,6 | 7,2 | 17,1 | 57,2 | 2,69 | 0,86 | 0,594 | 0,015 | 0,053 | 0,211 | 0,0051 | 0,561 |

At the Eti Alumina Plant, the extraction of Boehmite ($Al_2O_3 \cdot H_2O$) from Bauxite involves digestion of Bauxite in Caustic soda at high temperature, before separation of the residue from the supersaturated liquor. The design of the Eti process is rigorous, with very high caustic concentration, very fine grind of bauxite, and long autoclave holding time compared to many other alumina plants. The Eti Alumina Plant digestion process conditions indicate a very difficult to digest bauxite. The process in digestion can be represented chemically by the following equation.



The digestion process and its parameters are as below:

| Digestion Process Parameters | |
|------------------------------|--|
| Input | Bauxite slurry, Caustic soda and Steam |
| Output | Digested Slurry and Condensate |
| Process | Digestion of the slurry in caustic soda at high temperature to achieve a target blow-off caustic/alumina Molar ratio with an optimal flow. |

The amount of caustic added in this step is proportional to the concentration of alumina in the stream. Controlling this caustic/ alumina (MR) ratio in the digester is essential to process efficiency. Generally, the process is most efficient when the ratio is the closer to equilibrium MR. Most alumina plants using a monohydrate or boehmite containing bauxite, such as used at Eti Alumina Plant, charge the autoclaves to within 0.045 to 0.09 MR points of autoclave

equilibrium MR. The dangers of the overcharging are increased cost of processing and loss of capacity. Overcharging results in the following:

- Inefficient recovery of bauxite alumina. For plants that purchase bauxite and pay for expensive transportation, overcharging can be very expensive.
- For plants using high silica bauxite, overcharging significantly increases the specific consumption of caustic.
- Overcharging usually results in more than the losses that occur in the autoclaves. The alumina hydrate in bauxite that does not dissolve in the autoclave is now alumina hydrate in the red mud. This solid alumina hydrate acts as seed in the red mud thickeners and washers. This alumina precipitation is a loss of product alumina. To make up this loss, more bauxite, caustic, and steam are required.
- Consistently high overcharging or periods of massive overcharging can result in high solids in the overflow of the thickeners. This is an intolerable situation and must be corrected immediately to be able to operate the plant.

The continual concern of alumina plant operations is to charge as close to equilibrium MR as possible, thereby improving productivity and saving energy without a costly loss of bauxite and caustic.

A bauxite digestion test verifies that, under the process and facilities design of the Eti Alumina plant, significantly lower MRs are feasible. The original design of the target MR in the autoclaves is 1.65. The equilibrium MR for the same process conditions is about 1.325. The significance of this difference is that the liquor circulating in the plant has the theoretical capability of producing over 45 % more alumina. Conversely, the liquor circulating in the plant could theoretically be reduced over 30 % and still produce the same amount of alumina. The importance of this is that a large part of the steam required for autoclaves is proportional to the amount of liquor circulating.

The value of a lower MR at the Eti refinery is illustrated by the following figure:

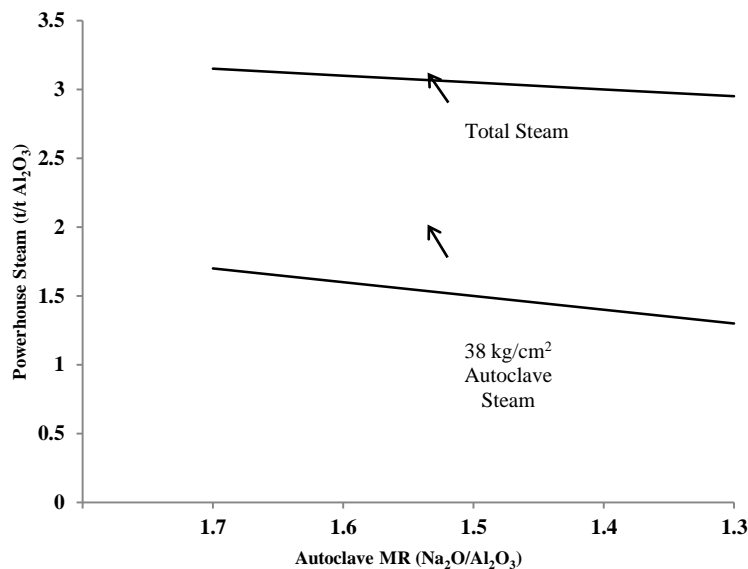


Figure 3. Powerhouse Steam Required vs. Autoclave MR

The high pressure steam to the autoclaves requirement decreases as expected because of the reduced liquor flow per unit volume of production. As the autoclave steam is reduced, there is somewhat less flash vapour available to send to the Evaporators. Because of this, the low

pressure power house steam to Evaporation must be increased to compensate. As a result, the reduction in total steam to process does not decrease as much as steam to the autoclaves. A compensating factor, however, is that the cost of low pressure (8 kg/cm²) Evaporator steam is about 74 % of the cost of high pressure (38 kg/cm²) steam. The cost effect of lower MR level is illustrated as follows:

Table 2. Cost effect of MR in Autoclave and Evaporation Section

| | | MR 1.65 | | MR 1.40 | |
|---------------------------------------|-------|------------------------------------|-------------------------------------|------------------------------------|-------------------------------------|
| | | Steam Usage | Cost | Steam Usage | Cost |
| | | t/t Al ₂ O ₃ | \$/t Al ₂ O ₃ | t/t Al ₂ O ₃ | \$/t Al ₂ O ₃ |
| Autoclave Steam Consumption and Cost | 15.49 | 1.7 | 26.33 | 1.29 | 19.98 |
| Evaporator Steam Consumption and Cost | 11.47 | 1.5 | 17.21 | 1.7 | 19.50 |
| Total | | 3.20 | 43.54 | 2.99 | 39.48 |

Boehmite Equilibrium Solubility

Below in Figure 4, Monohydrate Equilibrium Solubility in Eti Liquor according to a laboratory bomb digest test is plotted. This data can be used to determine the optimum target MR in the autoclaves.

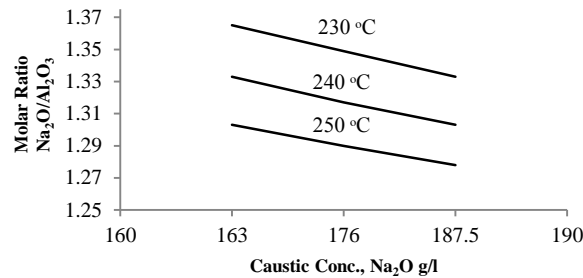


Figure 4. Monohydrate (Boehmitic) Alumina Equilibrium Solubility in Eti Liquor.

The laboratory study confirms the following about the Eti Alumina Plant bauxite:

- The processing of the bauxite by the Bayer process is predictable from its chemical analyses. For practical purposes the alumina is either in the form of boehmite or kaolinite.
- The alumina available for caustic dissolution can be dissolved up to the equilibrium solubility of boehmite well within the retention time of the Eti refinery autoclaves.
- The mud settling rate does not significantly change with lower MRs in the autoclave.

The above factors permit the Eti process to be operated at much lower MR levels in the autoclaves than called for in the original process design. The importance of this is that lower MRs will result in a significant reduction in the specific consumption of autoclave steam. Other observations resulting from the bauxite characterization study were:

- At lower MR levels in the autoclaves, the soluble silica level in plant liquor increases. Because of the increase in alumina yield at the lower MR levels, no increase in silica in

alumina product is expected. However, an increase in the rate of formation of silica scale can be expected in Digestion and Evaporation.

- At lower MR levels in the autoclaves, the “soluble” iron concentration in liquor will decrease significantly. It is expected, that with lower soluble iron concentrations and higher yields, the iron content of product can be lowered to approach 0.015 % Fe₂O₃. This depends, of course, on achieving normal performance in the operation of the liquor security filters (Kelly Filters) for particulate iron removal.
- Bauxite charge calculation factors should be modified to better reflect the result of autoclave chemical reactions.

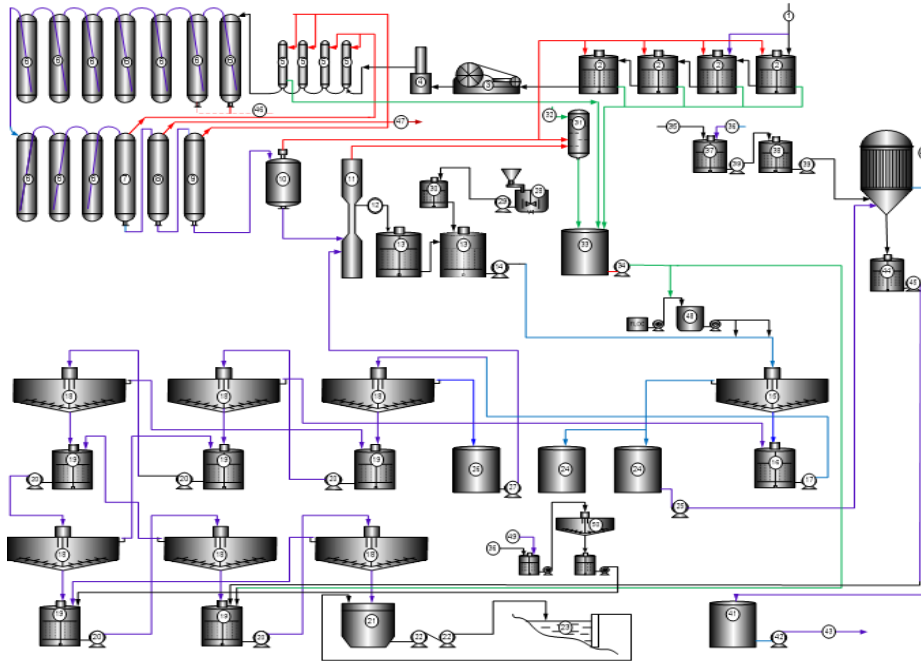


Figure 5. Schematic diagram of Eti high temperature digestion unit.

2.2. Evaporation

The Spent liquor from the precipitation section must be treated, heated, and recycled to the digestion autoclaves. Water is added to wash the red mud to recover caustic and adjust dilution of the pregnant liquor. Since the liquor continuously cycles through the plant, the water added must be evaporated so that the liquor volume can be controlled. Table 3 lists the input and exit streams that comprise the dilution balance in an operating plant. Efficiency demands that all of these flows be monitored.

Table 3. Input and Output Streams in Bayer Cycle

| Inputs | Losses |
|--------------------------------|-------------------------------------|
| residue wash | evaporation |
| sand wash | heat interchange flash |
| Al(OH) ₃ wash | Al(OH) ₃ to calcination |
| free moisture in bauxite | free water with Al(OH) ₃ |
| water in gibbsite and boehmite | water with residue |
| injected steam | evaporation from solution surfaces |
| purge water | |
| sodium hydroxide | |
| cleanup water (maintenance) | |
| uncontrolled dilutions | |

Generally, the evaporators in Bayer plants are multiple effect designs. In this configuration each effect operates at a lower pressure than the previous one. For that reason, the vapor evaporated from the liquor in the first effect is at a temperature high enough to heat the solution in the coming effect, providing the required boiling. At the final effect, the vapor enters a condenser. The condenser operates under vacuum so a vacuum pump is necessary to remove non-condensable gases from liquor. The more times the latent heat is used, or the more stages that are present in the unit, the more water can be evaporated by the fresh steam used in the first effect. The evaporation unit used in the Eti Bayer process to evaporate the water in spent liquor consists of a maximum of six effects. The reason for that is boiling point of the spent liquor is elevated 5–8 °C by the alumina and caustic in the liquor. This reduces the steam temperature in each effect; with many effects there is little temperature difference available to drive evaporation.

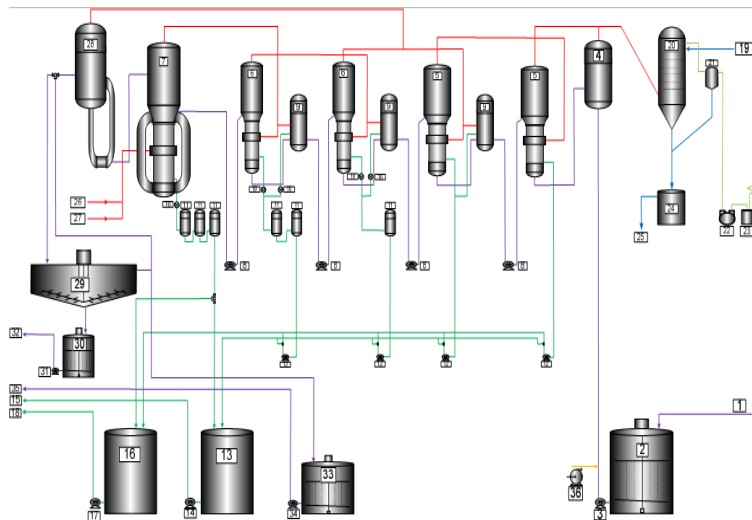


Figure 6. Eti Evaporation Unit

The Evaporators are designed to produce a liquor caustic concentration near 250 g/l Na₂O at near atmospheric boiling temperature. On the other hand, by substantially reducing the specific evaporation rate and holding the same precipitation caustic concentration, the caustic concentration of liquor to digestion will decrease. To operate the evaporator with lower evaporated liquor concentration will hurt the economy, because of the increase in outflowing

sensible heat. It is proposed to operate the evaporator at close to the product design concentration, and to by-pass a portion of spent weak liquor to mix with evaporator discharge to obtain the lower concentration required in digestion. This change requires a by-pass line with flow rate control instrumentation.

The liquor to digestion will be below atmospheric boiling temperature. This will put some sensible heat burden on digestion, but sensible heat losses between evaporation and digestion will be less.

A high caustic concentration after Evaporation is not necessary for the digestion of bauxite, and at lower MR levels, it is not necessary to satisfy the physical flow rate limitation of digestion. Evaporation is only needed to remove water added to process, and control the concentration of caustic liquor to digestion.

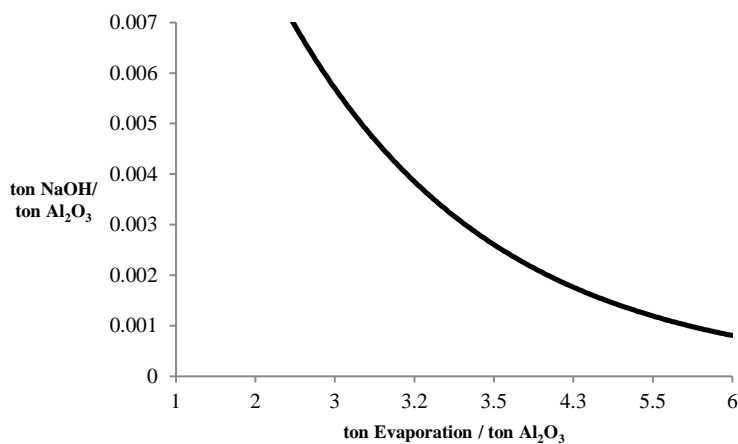


Figure 7. Red Mud Washers Net Caustic Loss vs. Evaporation

The Eti aluminium Plant process design calls for an Evaporation rate of 5.5 tons per ton of alumina. Reducing the evaporation rate to 3 T/T, only increases the caustic loss from 0.001 to 0.005 ton/ton. This is shown in figure 7. This is very small increase in caustic loss and a large reduction in Evaporation energy.

2.3. Summary of the energy optimization options in Alumina production

1. Lowering the molar Ratio

Lowering the molar ratio down to 1.40 in the autoclaves will require either of the following:

- Increasing the bauxite flow to wet grinding and holding the same digestion liquor caustic concentration
- Lowering the digestion liquor caustic concentration

The method to lower the molar ratio that has the best energy savings is to reduce the caustic concentration of liquor exiting evaporation and therefore reducing the demand for 8 kg/cm² boiler house steam.

2. By-pass the spent liquor to Evaporated exiting liquor

The evaporators are designed to produce an extraction liquor with a caustic

concentration of 250 g/l Na₂O. Operating the evaporators to produce a lower caustic concentration as required in digestion, will result in the evaporation economy suffering, increasing specific steam consumption (per ton of water evaporated). To maintain the higher evaporation economy, and produce a lower caustic concentrated liquor, a line will be installed to bypass up to 22 percent of the spent liquor around the evaporators, to then be mixed with the 250 g/l Na₂O liquor exiting evaporation.

3. Reduce Evaporation rate toward 3 T per ton Alumina production

It has been concluded that the wash water rate used at the Eti refinery is excessive. The red mud wash water consumption will be reduced from 5.5 ton/ton mud to 3 ton/ton mud, with just loss of 0.001 to 0.005 tonne caustic / tonne alumina.

3. Conclusions

Energy consumption in both digestion and evaporation will change when the molar ratio is adjusted and the evaporation economy is improved. The bauxite characterization study confirms that a lower molar ratio in the digestion autoclaves is feasible. This permits reducing liquor flow rate to digestion without reducing alumina production. The lower flow rate to digestion results in significant reduction in high pressure steam to Digestion, and an increase in low pressure steam to Evaporation.

This study highlighted the interrelationship of red mud washing and evaporation, and opportunity for process optimization with respect to energy conversation.

4. References

1. Den Hond, R. et.al., *Alumina Yield in the Bayer Process Past, Present and Prospects*, Light Metals 2007, p. 37
2. Wischnewski, R. et.al., *Alunorte Global Energy Efficiency*, Light Metals, TMS 2011 Annual Meeting, p. 179
3. H. Haraldsen et al. *Utilizing Waste Energy for Evaporation in the Bayer Process*, ICSOBA 2012
4. L. Liu et al. *Analysis of the overall energy intensity of alumina refinery process using unit process energy intensity and product ratio method* Energy 31 (2006) 1167–1176
5. Xiaofang Lou et al *Energy Consumption Optimization of the Aluminum Industrial Production Based on Pattern Recognition* Modern Applied Science Vol. 4, No. 10; October 2010
6. Qi Lijuan, Gu Songqing Wang Qingwei. *Comprehensive Energy Saving in China Alumina Industry* Light Metals 2005 p.35-40
7. K. Solymar et al. *Co-processing of Different Types of Bauxite with High Efficiency* Light Metals, 2001, p.105.
8. Gu Songqing et al. *Energy Saving in Bayer Process* , Light Metals, 2007.