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ALUNORTE GLOBAL ENERGY EFFICIENCY

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Abstract

Alunorte is the largest alumina refinery in the world with a production capacity of close to 6.3 Mtpy. The plant has a specific energy utilization of 8 GJ per ton of alumina and is one of the most energy-efficient plants in the world. The high energy efficiency is achieved by good process design, the utilization of state-of-the-art technologies, good operation and the processing of high quality bauxite. The technologies which are applied in Alunorte to contribute to the global energy efficiency of the plant are reviewed and heat integration and water balance are discussed.

Introduction

Alumina is the principal raw material for aluminium. In 2009 the world-wide average utilization of electrical power for primary aluminium production was 15,215 kWh per metric ton of aluminium [1]. The energy for alumina production is not included and has to be added. The average energy utilization for alumina production was 3,311 kWh per ton of alumina in 2009 [2]. In theory 1.9 tons of smelter-grade alumina are required for the production of one ton of primary aluminium. Hence, energy-efficient alumina production is an important contribution to reduce the energy utilization of primary aluminium production.

Table I. Energy used for 2009 alumina production [2].

	spec. energy (MJ/t)	alumina produced (t)
Africa and South Asia	14,768	3,225,778
North America	11,449	2,804,849
South America	9,319	12,226,990
East Asia and Oceania	11,252	16,511,664
Europe	16,842	7,117,522
Weighted Average	11,922	--
Total	499,355 TJ	41,886,803

Table I shows the 2009 specific energy utilization for alumina production by region. On average the production in South America utilizes less energy than in any other region of the world. Alunorte contributes significantly to this result. The production capacity of Alunorte is close to 6.3 Mtpa after its third expansion in 2008 [3]. Alunorte produces close to 50 % of all alumina in South America. Its energy utilization was 8.0 GJ per ton of alumina in 2009. This is significantly less than the average of 9.3 GJ per ton in South America and 11.9 GJ per ton world wide. In Figure 1 Alunorte's performance is compared to the energy utilization of other alumina refineries. The graph includes alumina plants for the production of smelter-grade alumina outside China. The statistic illustrates that the world-wide benchmark for alumina production is at about 8 GJ/t. There are few plants only with a similar good performance. In the following, the different factors are discussed which in sum result in high global energy efficiency of Alunorte. Main elements are bauxite of high quality, the precipitation concept and the resulting high liquor productivity. Alunorte's design with regard to heat integration, water balance and utilities for steam and power generation is discussed as well as technology and equipment applied. Some factors are mentioned which work against an improvement of energy efficiency in the future. Current projects to address these issues are mentioned and some possibilities for a further increase of energy efficiency are presented. Alunorte has the aim to be among the most energy-efficient alumina refineries in the world also in the long-term.

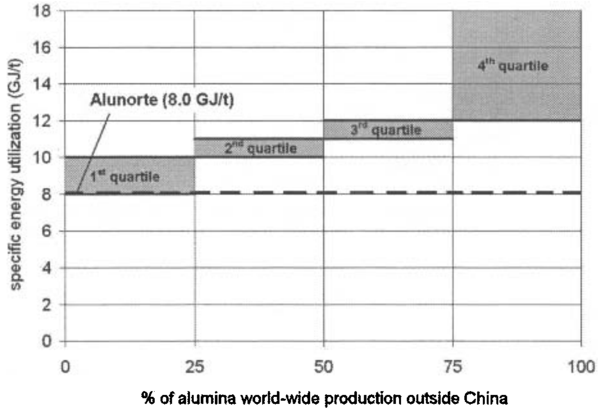

Figure 1. Specific energy utilization for alumina production.

Energy Utilization for Alumina Production

Alunorte started operation in 1995 with a production capacity of 1.1 Mtpy. Since then the plant was expanded three times to a total production capacity of close to 6.3 Mtpy. In Figure 2 the development of production capacity is shown and compared to the energy utilization of the plant. In 2009, the first year after Expansion 3, the actual production remained slightly behind the nameplate capacity of the plant. The Expansion 3 project, Alunorte's current performance and an outlook about the expected development of Alunorte are presented in [3].

After the first two years of operation, the plant uses between 7.5 GJ and slightly above 8 GJ per ton of alumina. In 2006 the best result was achieved. In the following years from 2006 to 2009, i.e. since Expansion 2, the specific energy utilization trends upwards. With Expansion 2 some new technologies were installed. Bauxite is received from Paragominas through a pipeline and dewatered at Alunorte in hyperbaric filters. The filters use compressed air and thus compressor power. Two more turbogenerators were installed to increase the electrical power which is co-generated at site. The losses of cogeneration of electr-

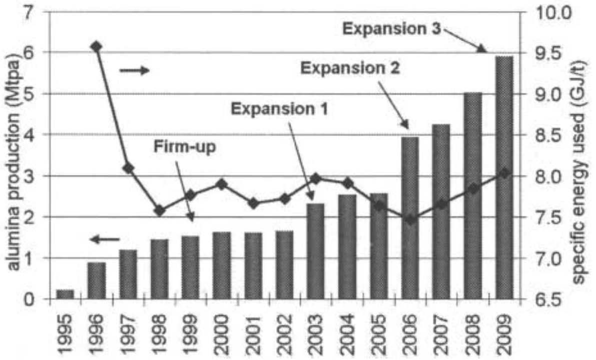

Figure 2. Development of Alunorte's alumina production capacity and specific energy utilization.

icity decrease Alunorte's global energy efficiency. Losses of cogeneration are included in Alunorte's overall efficiency while electricity from the grid is accounted as is without adjusting for losses during generation. The plant availability reduced somewhat which is associated with some negative impact on the specific energy consumption as Alunorte became more complex.

In Figure 3 a breakdown of the energy utilization of Alunorte is shown. It is divided into electrical power received from the national grid, energy required for steam and power generation and energy for calcination. The energy for steam and electricity generation and calcination is based on the lower heating value (LHV) of the fuels. Electrical energy received from the national grid is accounted as received and is not adjusted for losses during generation. Steam at two pressure levels can be generated with the installed high pressure or low pressure boilers. Three turbo-generators work between the high and the low pressure level and can cogenerate up to 65 % of the required electrical power of Alunorte. Process steam is supplied to the process from the low pressure header. In digestion about 1.0 t steam per ton of alumina is consumed and about 0.2 t/t in evaporation. 3 GJ per ton alumina is used for calcination. Other consumers include losses due to inefficiencies of boilers and turbogenerators, internal steam consumption in the boilers and miscellaneous steam consumers in the process such as for filter aid preparation.

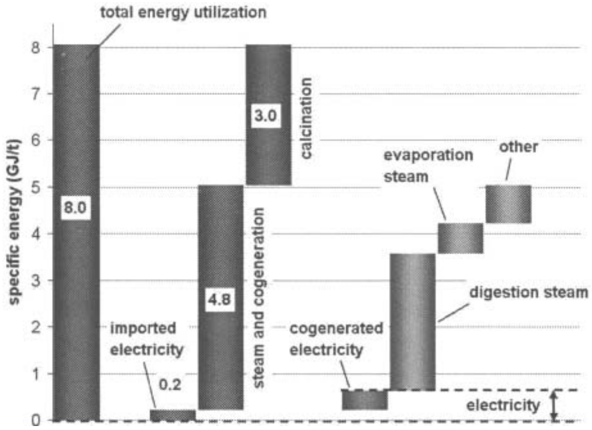

Figure 3. Breakdown of energy used at Alunorte.

Bauxite Quality & Liquor Productivity

The bauxite quality, in particular the content of available alumina, reactive silica and organic components, significantly affect the performance of an alumina refinery. Alunorte processes high quality bauxites from two different sources, namely Trombetas and Paragominas. Table II compares the main characteristics of these bauxites.

Table II. Typical bauxite quality.

	Trombetas	Paragominas
available Al_2O_3	49.1 %	48.2 %
reactive SiO_2	4.1 %	4.6 %
organic carbon	< 0.05 %	< 0.05 %
moisture	11.5 %	14.9 %

Although the composition is very similar certain differences are observed during processing. The high content of available alumina results in a low specific bauxite consumption. This is beneficial in terms of energy utilization, since the amount of the non-gibbsite fraction of bauxite, which does not contribute to the production of hydrate, is small. A low amount of digestion live steam is required only to heat up this material with a positive effect on the overall energy efficiency. A low temperature digestion process is used at Alunorte as both bauxites contain minimal amounts of boehmite. Their reactive silica content, however, is relatively high. The reactive silica reacts under consumption of caustic soda to desilication product (DSP) and increases the amount of bauxite residue. Generally, some heat is lost from the process to the environment due to the bauxite residue having a temperature of about 60 °C upon disposal. This heat loss at Alunorte, however, is moderate due to the relatively low mud factor, e.g. mass of mud per mass of alumina produced, which caused by the high content of available alumina in the bauxite and the bauxite residue being filtrated before disposal.

Table III. Spent Liquor Analysis.

Al_2O_3	(g/l)	112
NaOH (as Na_2CO_3)	(g/l)	280
Na_2CO_3	(g/l)	5.6
causticity	(%)	98
organic carbon	(g/l)	4.4
NaCl	(g/l)	2.20
Na_2SO_4	(g/l)	0.28
$Na_2C_2O_4$	(g/l)	< 0.1

The content of organic material in the bauxite is very low. This results in a very low concentration of impurities in the plant liquor. In Table III a spent liquor analysis of Alunorte is shown. The concentrations of organic carbon, sulfate and oxalate are low and the causticity of the liquor is very high. The plant is operated with a high caustic concentration. A precipitation productivity of up to 89 g/l in the newest process lines can be achieved [3].

The concept of bauxite residue treatment and disposal is an important factor contributing to high liquor purity. Bauxite residue is filtered in drum filters and disposed at high solids concentration by dry stacking in the residue disposal area (RDA). Collected water from the RDA is neutralized and clarified in a water treatment station and released as effluent to the nearby river [4]. There is no water returning from the RDA to the process. This approach avoids the contamination of plant liquor with additional impurities and contributes to maintain clean liquor with high liquor productivity. Liquor impurities are purged from the process with the bauxite residue. No caustizisation unit for carbonate removal is installed.

Process Design

The concepts for heat integration, water balance and generation of steam and electrical power are the main contributors for direct savings of energy.

Heat Integration

Alunorte has a low temperature dual stream digestion unit. A simplified flowsheet is shown in Figure 4. The pregnant liquor stream is expanded and flashed in five stages from the digestion temperature and pressure to atmospheric conditions. The liquor is released from the blow-off tank (BOT) at a temperature close to the liquor boiling point. The spent liquor is heated in counter-current flow by regenerative heating. Heat is transferred from the pregnant liquor to the spent liquor stream with vapor from the flash tanks which is condensed in four spent liquor regenerative heaters. Vapor from the blow-off tank is released to the environment. Live steam heaters are used to heat the spent liquor to the required temperature before it is fed to the digestors.

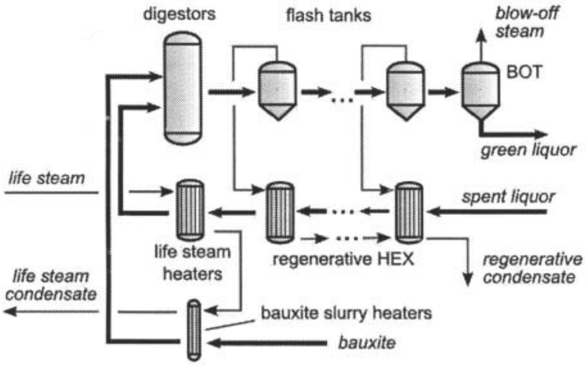

Figure 4. Simplified flowsheet of digestion and slurry heating.

A conceptual problem of dual stream digestion technology is the difference between heat sink (spent liquor) and heat source (pregnant liquor). The mass flow of pregnant liquor is larger than that of spent liquor by the amount of bauxite slurry which is charged to the digestors. It is not possible to condense all vapor which is flashed from the pregnant liquor stream in the regenerate heat exchangers and transfer all latent heat of the vapor to the spent liquor. The excess steam leaves the blow-off tank and is a loss of heat to the environment. In plants with large amounts of excess steam some of it can be transferred to other process areas.

At Alunorte the difference of heat sink and heat source in the digestion area is small and with it the loss of heat to the environment. This is based on a good design of Alunorte. There is no direct heating of the spent liquor by steam injection and indirect bauxite slurry heaters are installed. Direct heating increases the difference between heat source and heat sink in digestion, an additional amount of water must be evaporated and requires additional energy and the caustic concentration drops due to dilution with steam. The upper limit for the caustic concentration is given in the spent liquor live steam heaters due to scaling and corrosion. At lower caustic concentrations less bauxite can be charged to the liquor and liquor productivity decreases. These negative effects are minimized at Alunorte due to avoiding direct heating by steam injection. Furthermore, the heat exchange area for spent liquor heating is well chosen, so that the energy for regenerative spent liquor heating is high.

Indirect heating of the bauxite slurry is another important contributor to low digestion steam consumption. The digestion temperature is a mixing temperature determined by the temperature and mass flows of the bauxite slurry and the final spent liquor temperature. The higher the temperature of the bauxite slurry the lower the final spent liquor temperature after the last live steam heater can be. This reduces the utilization of digestion live steam and increases the global energy efficiency.

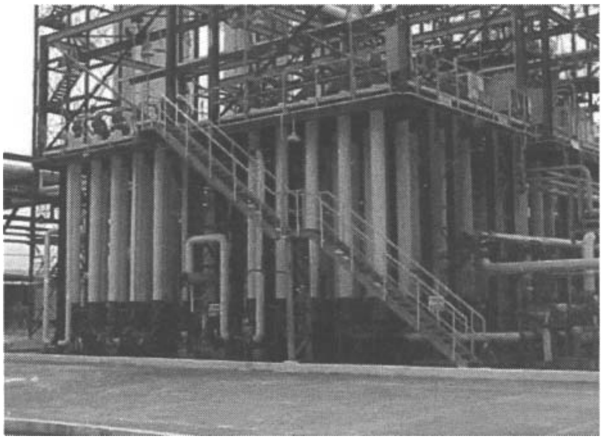

Figure 5. Indirect Bauxite Slurry Heaters (IBSH).

Two stages of Indirect Bauxite Slurry Heaters (IBSH) are installed at Alunorte. The aim is to achieve the highest possible bauxite slurry temperature. The IBSH units are vertical shell-and-tube heat exchangers (Figure 5). The bauxite slurry is heated indirectly with live steam heater condensate. Alunorte operates the units without major problems. As part of Alunorte's continuous efforts to increase heat recovery a project has been launched to add a third stage of IBSH and maximize the bauxite slurry temperature before digestion. This will reduce digestion live steam consumption due to a lower required final spent liquor temperature. Furthermore, a positive effect on the silica scaling in the spent liquor heat exchangers is expected. A good maintenance program is in place to keep the heat transfer coefficients of the heat exchangers in the digestion area at a high average level.

The efficiency of the vacuum flash cooling units is another major contributor to the low energy utilization of Alunorte. Pregnant liquor is cooled in counter-current flow against spent liquor in a flash train. The pregnant liquor inlet temperature is close to the boiling point and the outlet temperature shall be as low as possible. Additional plate heat exchangers are used to achieve the final fill temperatures to agglomeration and cementation tanks. A simplified flowsheet of Alunorte's vacuum flash unit and plate heat exchangers is shown in Figure 6.

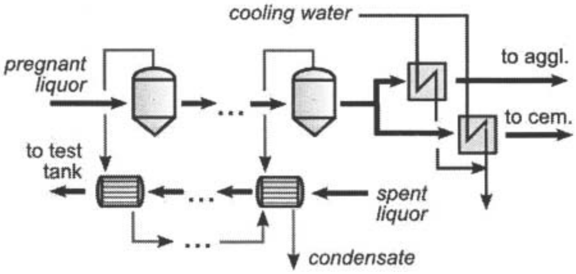

Figure 6. Vacuum flash cooling and plate heat exchangers.

The better the performance of the vacuum flash cooling units the lower is the pregnant liquor inlet temperature to the precipitation plate heat exchangers. This reduces the requirement of cooling water to the plate heat exchangers and recovers more energy for heating the spent liquor. A high spent liquor temperature reduces the required amount of digestion live steam and improves the performance of the evaporation unit. Alunorte has a spare vacuum flash cooling unit so that cleaning and maintenance can be performed without major performance losses in three of the seven lines. A high average heat transfer coefficient of the heat exchangers of the vacuum flash cooling units can be achieved and process disturbances due to cleaning are small in these lines. As measure for higher average heat transfer coefficients Alunorte optimizes the cleaning cycles of the vacuum flash cooling units and will study the option to install spare vacuum flash cooling units for the other four lines as well. For efficiency improvement their capacity could be increased such that lower pregnant liquor and higher spent liquor temperatures can be reached.

Water Balance

The water balance directly affects the energy utilization of an alumina refinery. It is unavoidable that water from different sources dilutes the plant liquor. This water is mainly removed by evaporation. With higher rates of liquor dilution the demand for evaporation increases and at the same time energy used in form of live steam.

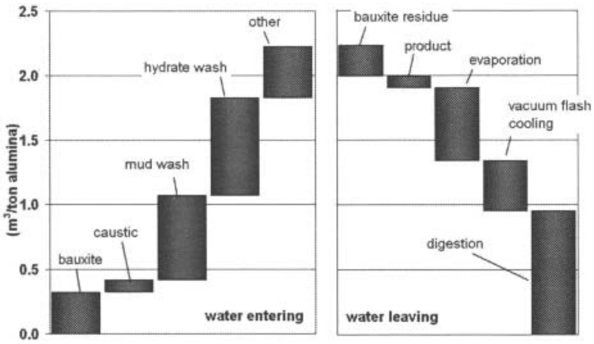

Figure 7. Volume of water entering and leaving the plant liquor.

In Figure 7 the water balance of Alunorte is shown. Due to a high liquor productivity and no direct heating with steam in digestion dilution of liquor with water per ton of alumina can be kept at around 2.3 m^3/t. Main sources are the moisture content of the bauxite, water for mud and hydrate washing, a small amount entering with caustic and various sources such as hose water, lime slaking, gland water, rain, etc. Alunorte's digestion concept which avoids dilution of liquor and uses indirect heating only is one of the main reasons for a comparably small liquor dilution.

Trombetas bauxite is transported to Alunorte by ship while Paragominas bauxite is pumped through a 244 km pipeline [5]. At Alunorte the Paragominas bauxite is dewatered in hyperbaric filters [6-8]. The residual moisture of the dewatered bauxite is about 15% and slightly higher than that of Trombetas bauxite with about 11.5 %. The moisture content of the dewatered Paragominas bauxite is determined by the performance of the filters and the characteristics of the bauxite, in particular its particle size distribution. Work is underway to optimizing the operation of the filters in cooperation with the beneficiation plant of Mineração Bauxita Paragominas (MBP). The potential for improving the water balance in bauxite filtration, however, is small. The same is valid for water entering with fresh caustic. It is supplied at a concentration 50 wt.-% NaOH. The caustic consumption is mainly determined by the non-controllable loss due to the content of reactive silica in the bauxite and the controllable losses which are affected by the efficiency of mud washing and the residual moisture in the bauxite residue. Controllable losses are already very small with less than 8 kg of caustic per ton of alumina. However, some potential improvements in the bauxite filtration area identified.

Regenerative condensate is used for washing bauxite residue and hydrate. Both together are the biggest source of plant liquor dilution. The net wash of mud is generally good with 0.8 - 1.2 ton of water per ton of mud. The potential for further improvement is small. The situation for hydrate washing is similar good and the potential for improvements small. Dilution of plant liquor from other sources such as rain, water hosing or gland water is moderate. All tanks are closed and water hosing is done with care. There exist some possibility for further reduction of water input to the liquor but the situation is generally good and room for improvement also small.

Small water sinks are product and bauxite residue while the largest part of the water is removed by evaporation in three plant areas – digestion, vacuum flash cooling and evaporation. A good maintenance program is crucial to ensure high average heat transfer coefficients in all heat exchangers of these areas. A high heat transfer coefficient is associated with a high rate of water removal from the liquor and low consumption of live steam in the digestion and evaporation areas. Furthermore, spent liquor return temperature increases with higher performance of the vacuum flash cooling units. The demand for digestion life steam reduces and the efficiency of the evaporation area increases which is associated to a lower requirement for evaporation live steam. Work is underway to further improve the performance of the flash trains in the digestion, evaporation and vacuum flash cooling.

Steam and Power Generation

The design of the utilities area for steam and power generation has to match the demand of steam and electrical power. Inadequate design can lead to high losses in this area and potential savings in steam or electrical power in the Bayer process would be compromised by additional losses in the utilities area. Alunorte has chosen a design which allows a sufficient flexibility to achieve overall high efficiency in steam and power generation.

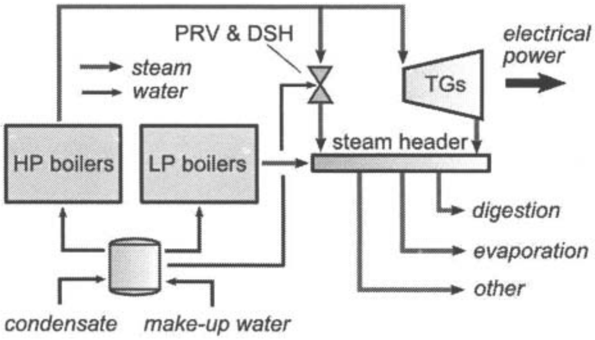

Figure 8. Simplified flowsheet of utilities area for steam and power generation.

A simplified flowsheet is shown in Figure 8. Alunorte receives some of the electrical energy from the national grid and co-generates the remaining electrical energy with turbogenerators (TG) which work between the high pressure (HP) and low pressure (LP) steam headers. The fraction of the high pressure steam (87 bar and 485 °C), which is not required for cogeneration, passes through pressure reducing valves (PRV) and is subsequently cooled to saturated conditions by adding water in desuperheaters (DSH). This amount of high pressure steam can be replaced with steam from the low pressure boilers. Thus, the generation of steam and electrical power are not directly coupled but allow some operational flexibility. The operation of the utility area for steam and power generation can be optimized under consideration of overall efficiency and operational cost. The high pressure boilers have an efficiency of 84-86 % while that of the low pressure boilers is 88-90%. The second advantage of decoupling of steam and power generation is that a design could be chosen which avoids the installation of condensing turbines, resulting in an overall higher efficiency of the utility area.

A high boiler feed water temperature is beneficial for the overall efficiency for steam generation. Some of the boiler feed water is preheated in the calcination area. Potential for further improvement is identified in the rate of live steam condensate from the process. The fraction which does not return is replaced by make-up water. Due to its lower temperature the power plant efficiency decreases with the fraction of make-up water. Alunorte works on a project which will increase the condensate return rate. Some more potential for efficiency improvement exists when higher steam parameters are chosen. 160 bar and 540 °C are typical ranges for circulating fluidized bed boilers [9]. However, this can only be implemented as part of the construction of a new boiler. Furthermore, it needs to be carefully studied if these boilers are suitable as utility boilers of an alumina refinery.

Technology, Operation & Maintenance

The potential for direct savings of energy in precipitation (from the first precipitation tank onwards) is limited. Indirectly, however, energy is saved when the productivity of the liquor is maximized. High liquor productivity is important for low specific energy utilization. The higher the liquor productivity the lower is the amount of liquor which has to be heated up in the digestion area and cooled down in the precipitation area per ton of alumina produced. The specific steam consumption in digestion and thus specific consumption of boiler fuels is low. Alunorte is operated at high caustic concentrations and at a high liquor to precipitation (LTP) A/C ratio. Seed filtration is used in five of the seven lines and in two lines cyclones for seed concentration are installed. With the precipitation concepts chosen in Alunorte high liquor productivities are achieved.

In addition, it is important that the individual pieces of equipment of the plant have a high efficiency, operational procedures are good, high availability can be achieved and a good maintenance program is in place. High efficiency motors for agitators, blowers, etc. are installed and pumps with variable speed or variable frequency drives. An electrical power utilization less than 0.2 MWh per ton of alumina is achieved.

Steam consumption is significantly affected by the process design as explained above. But also individual units, in particular the evaporation area, have to perform well. Alunorte's evaporation units have an efficiency of about 4.2 ton evaporated steam per ton of live steam. Some potential for improvement was identified and Alunorte works on a project for further performance increase.

A major operational issue is scaling. It affects the heat transfer coefficient in heat exchangers and has an impact on the overall availability of the plant in dependence of the frequency for de-scaling and cleaning. Both are associated with lower global energy efficiency. Alunorte works on the one hand to optimize the cleaning and descaling work and on the other hand to reduce scaling rates. Measures to reduce the solids concentration in spent liquor are one example. Another is the modification of digestion side entry flash tanks to bottom entry which was done before Expansion 1. Today there are no side-entry flash tanks installed at Alunorte. Carry-over of caustic reduced and longer cleaning intervals could be achieved. Benefits can also be achieved from chemical agents to reduce scaling.

Calcination is a major contributor to the energy used for alumina production. The theoretically achievable limit is 2.4 GJ/t, when the enthalpy of formation for aluminium trihydrate and alumina are compared. This value does not consider energy used for the evaporation of remaining moisture in the filtered trihydrate and other technical limitations, such as a minimum stack temperature of the flue gas. Alunorte uses circulating fluidized bed calciners which use on average 3 GJ/t of energy. Alunorte received the energy efficiency award 2010 for the two newest calciners by the German Energy Agency which operate at 2.79 GJ/t [10].

Conclusions

Alunorte's is one of the most energy-efficient alumina refineries in the world. The main contributors to this performance are discussed, such as the utilization of high quality bauxites, a good process design, the use of energy-efficient calciners and efficient steam and power generation. The heat integration concept and water balance of the refinery are presented. A good heat integration concept is chosen and Alunorte uses indirect heating only and avoids dilution of plant liquor with steam. Other liquor dilution is generally small. Net wash for example is small. The layout of the utilities area for steam and electrical power generation allows a good operational flexibility and has a generally high efficiency. Alunorte is aware of some factors with a negative impact on energy efficiency. Slowly decreasing bauxite quality, a higher rate of cogeneration of electricity or the ageing of the plant are examples. Alunorte addresses these issues and works on a number of projects to implement process improvements, e.g. in bauxite dewatering, bauxite slurry heating, precipitation and bauxite residue filtration. Furthermore, cleaning cycles for descaling of heat exchangers are optimized. Alunorte will continue to identify potential for improvement of energy efficiency and aims to be one of the most energy efficient alumina refineries in the world – also in the long term.

References

1. International Aluminium Institute (IAI), "Electrical Power used in Primary Aluminium Production", online content, "https://stats.world-aluminium.org/iai/stats_new/formServer.asp?form=7", date of issue Sept 2, 2010.

2. International Aluminium Institute (IAI), "Energy used in Metallurgical Alumina Production", online content, "https://stats.world-aluminium.org/iai/stats_new/formServer.asp?form=8", date of issue Sept 2, 2010.

3. Daryush A. Khoshneviss, Luiz Gustavo Corrêa, Joaquim Ribeiro Alves Filho, Hans Marius Berntsen and Ricardo Carvalho, "Alunorte Expansion 3 – The new lines added to reach 6.3 million tons per year", In *Light Metals 2011*, Lindsay, S., Ed., TMS (The Minerals, Metals & Materials Society).

4. Jorge Aldi, "Achieving Excellence in Liquid Effluent Treatment at Alunorte", In *Light Metals 2009*, Bearne, G., Ed., TMS (The Minerals, Metals & Materials Society).

5. Ramesh Gandhi, Mike Weston, Maru Talavera, Geraldo Pereira Brittes and Eder Barbosa, "Design and Operation of the World's First Long Distance Bauxite Slurry Pipeline", In *Light Metals 2008*, DeYoung, D.H., Ed., TMS (The Minerals, Metals & Materials Society), 95-100.

6. Ayana Oliveira, Juarez Dutra and Jorge Aldi, "Alunorte Bauxite Dewatering Station – A Unique Experience", In *Light Metals 2008*, DeYoung, D.H., Ed., TMS (The Minerals, Metals & Materials Society), 85-87.

7. R. Bott, T. Langeloh and J. Hahn, "Filtration of Bauxite after Pipeline Transport: Big Challenges – Proper Solutions", In Proceedings of *8th International Alumina Quality Workshop*, Armstrong, L, Ed., AQW Inc.,2008, 319-323.

8. A. Campos, R. Bott, "Determination of a suitable dewatering technology for filtration of bauxite after pipeline transport". In *Light Metals 2008*, DeYoung, D.H., Ed., TMS (The Minerals, Metals & Materials Society).

9. Stephen J. Goidich and Ragnar G. Lundqvist, "The Utility CFB Boiler – Present Status, Short and Long Term Future with Supercritical and Ultra-Supercritical Steam Parameters", Proceedings of *Circulating Fluidized Bed Technology VII – Proceedings of the 7th Int. Conf. on Circulating Fluidized Beds*, Grace, J.R., Zhu, J-X., de Lasa, H.I., Eds. Can. Society of Chemical Engineering, Ottawa, May 2002.

10. Michael Missalla, Hans Werner Schmidt, Joaquim Ribeiro Alves Filho and Reiner Wischnewski, "Significant Improvement of Energy Efficiency at Alunorte's Calcination Facility", In *Light Metals 2011*, Lindsay, S., Ed., TMS (The Minerals, Metals & Materials Society).