# ALUNORTE EXPANSION 3 – THE NEW LINES ADDED TO REACH 6.3 MILLION TONS PER YEAR

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Keywords: Expansion Project , Alunorte Performance, Plant Management

## Abstract

Alunorte started operation in 1995 with a design production capacity of 1.1 Mtpy. Since then the plant was expanded three times and consists today of seven production lines with a total production capacity of close to 6.3 Mtpy. Expansion 3 included the process lines 6 and 7. The lines were commissioned in 2008 and reached their nominal production capacity after a short start-up phase.

In Expansion 3 a number of new technology developments were consolidated, such as the bauxite transport by pipeline, an improved precipitation concept and others. The impact of the process modifications applied in lines 6 and 7 are discussed in comparison to the previous lines with regard to effects on production volume, productivity, alumina quality and availability.

However, a number of challenges are associated with the operation of a plant of the size of Alunorte which has grown very fast: the management of seven process lines, the operation of the plant with a very young organization and strong demand for training.

## Introduction

Alunorte started operation in July 1995. The plant had two production lines and a nominal production capacity of 1.1 Mtpa. This production rate was reached in 1997 and exceeded in the following years. A number of process improvements were implemented so that the production capacity could be increased to 1.6 Mtpa in 2000. In eight years only from 2000 to 2008 the plant production capacity increased three times. Work on Expansion 1 started in 2000 and in the first quarter 2003 the third process line was commissioned. The plant design production capacity was increased to 2.325 Mtpa. This production rate could be reached and even exceeded during the first year after the expansion. In 2006 process lines 4 and 5 were commissioned as part of Expansion 2. The production capacity increased further to close to 4.4 Mtpa. This number includes a firm-up of the precipitation area of lines 1-3. Finally, in the fourth quarter of 2008, lines 6 and 7 started operation as part of Expansion 3. The plant has now a nominal production capacity of close to 6.3 Mtpa.

In Fig. 1 the development of production capacity and actual production are shown. The graph makes clear that historically Alunorte exceeded the expectations with regard to production volumes. For Expansion 1 and 2 the actual production before the expansion – which were higher than design – was the design basis onwards. In this way additional production volume is included in today's nameplate production capacity of close to 6.3 Mtpa when compared to the production volume of the original plant and the expansions. Before Expansion 2 was commissioned Alunorte ex-

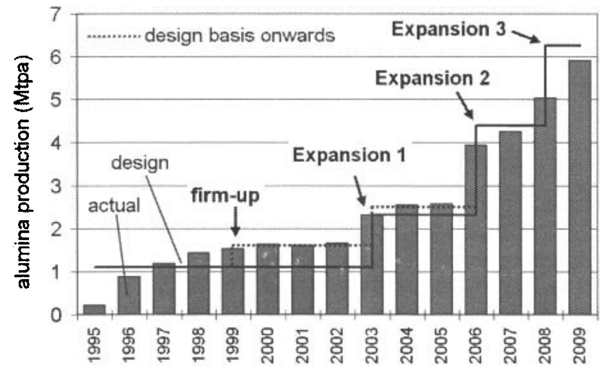


Figure 1. Development of production capacity of Alunorte.

ceeded well its design production capacity. From Expansion 2 onwards the actual production remains slightly behind the design production capacity. However, all lines individually have demonstrated their design capacity. But the plant has become more and more complex with time. A number of issues arose which are linked to the size of the plant and its fast growth. On the other hand operations, maintenance, logistics can be made very efficient and a number of benefits can be achieved.

In the following, the Expansion 3 project is described followed by a review of Alunorte's current performance. Then the current main challenges are discussed – technically and organizationally. Some of the projects started to improve the situation are presented as well as an outlook about Alunorte's expected development and performance.

## Scope of the Project

Expansion 3 consists of new filters for bauxite dewatering, two new process lines (lines 6 and 7), two 3,300 t/d calciners, a port expansion and the construction of a new high-pressure circulating fluidized bed (CFB) boiler. This paper focuses on the implementation of the new process lines from bauxite dewatering to calcination and discusses port expansion and boiler erection briefly.

The design of the new process lines 6 and 7 is partly based on the original design of Alunorte of Alcan International from 1995, partly it includes improvements which have been implemented in the previous expansions and some new elements were added. The most obvious difference between the expansions is their size. Each of the new lines has a nominal production capacity of 930 ktpa or 1.86 Mtpa in total for Expansion 3. The original design capacity of the plant was 1.1 Mtpa, 550 ktpa per line. Thus, the design capacity of lines 6 and 7 is about 70% larger than the original design capacity of the first two lines. The dimensioning of the new lines is larger than that of the old ones but also the process performance considerably increased. In 2000, after the firm-up, lines 1 and 2 produced 1.6 Mtpa and operated at a precipitation productivity of close to 84 g/l. With lines 6 and 7 a precipitation productivity of 89 g/l can be achieved. This is a result of the continuous improvement of the precipitation concept. Lines 1/2/3, 4/5 and 6/7 apply three different concepts. In lines 6/7 coarse seed and fine seed filtration are installed, lines 4/5 use seed cyclones and lines 1/2/3 coarse seed filtration. The newest lines are operated with the highest solids concentration and achieve the highest precipitation yield. Furthermore, the cooling capacity is well dimensioned. In addition to traditional in-tank plate heat exchangers external plate heat exchangers (Barriquand coolers) are installed. The number of tanks has been increased as well as their size in order to increase residence time for higher precipitation productivity.

The bauxite for lines 6 and 7 is supplied from Mineração Bauxita Paragominas (MBP) through the world's first long-distance bauxite slurry pipeline [1]. The bauxite slurry is pumped at a solids content of 50 % and is then dewatered at Alunorte in hyperbaric filters [2,3]. A residual moisture content of about 15 % in the dewatered bauxite is achieved. This is slightly higher than that of Trombetas bauxite which arrives by ship. To be pumpable through the pipeline the Paragominas bauxite is finely ground at MBP. Its particle size distribution is sufficiently fine to be charged to the Bayer plant without additional milling. Different to the other lines no mills are installed in lines 6 and 7 and the bauxite is sent from filtration by conveyor belts directly to the bauxite slurry re-suspension tanks and heating units.

The clarification area has undergone a number of changes compared to the original design. Initially conventional decanters and washers were installed. As part of the expansions deep thickeners were added. Alunorte made good experience with their operation so that in Expansion 3 only deep thickeners are installed and conventional decanters or washers are completely eliminated. As part of Expansion 3 Alunorte has decided to install Diastar filters for liquor filtration. The filters are operated fully automatically. The operational performance of the liquor filtration area could be improved in comparison to the previous process lines.

In digestion, evaporation and vacuum flash cooling bottom-entry flash tanks are installed. The carry-over of caustic soda to the condensate is lower than for conventional side-entry flash tanks. The regenerative condensate has better quality, the scaling in the vapor transfer lines is reduced and longer cleaning cycles are achieved. Originally side-entry flash tanks were installed in digestion lines 1 and 2. These were modified to bottom entry and in all expansions only bottom entry tanks were used.

A modern fully digital fieldbus process control system is installed. At Expansion 2 it was decided to complete the move from an analog system to a digital system. This system is implemented as part of Expansion 2 and Expansion 3. The degree of automatic control increased with each expansion. The high degree of automatic control of the new lines helps to achieve higher overall performance in the new lines.

The performance of the calcination facilities was increased again with Expansion 3. The energy efficiency of the new two 3,300 t/d circulating fluidized bed (CFB) calciners is higher than that of the old ones. A high degree of automatic control is installed [4]. In total seven CFB calciners of Outotec (formerly Lurgi) are installed. Alunorte received the energy efficiency award 2010 from the German Energy Agency for the two newest calciners [5].

A part of the electrical power used by Alunorte is co-generated at site while the rest is received from the national grid. As part of Expansion 3 a circulating fluidized bed boiler was installed. The utilities system for steam and electrical power generation of Alunorte has a high overall efficiency and good operational flexibility. This is important in order to be able translate the low specific consumption of steam and electrical power into a low specific consumption of boiler fuel.

The environmental concept is continued with Expansion 3 in order to guarantee a generally high standard. Emissions and effluents are within the legislative limits. Of high importance is Alunorte's bauxite residue disposal concept – dry-stacking – which is state of the art. The mud in filtered in drum filters and then disposed at high solids concentrations. Water from the bauxite residue area (RDA) is collected, cleaned and then send to a nearby river.

## Project Execution

The installation of process lines 6 and 7 as part of Expansion 3 was finished on schedule, on budget and the design performance of the two new lines could be demonstrated during the first two months after start-up. The project had a duration of 32 months. The master schedule of the project for the refinery is shown in Fig. 2.

A number of factors contributed to the fast execution of the project. One of them was the strategy to use the latest expansion as design basis for the new lines. Improvements in specific plant areas were included. However, the concept was not fundamentally changed in most areas. The biggest differences are found in precipitation. The project was executed with an extended owners' team with no EPCM contractor. Alunorte Board of Directors acted as steering committee for the project. An advantage of the organization of the project was the ability to take decisions very fast and avoid decision-related delays of the project. Furthermore, it was possible to work with a very experienced team. Most members of the Alunorte expansion team have already been involved in the previous expansions. Finally, it was possible to perform the start-up of the lines earlier than originally scheduled. Less time than planned was required to reach the nominal production capacity of lines 6 and 7.

The project completion system ProCoSys™ was used for construction and commissioning of the new lines. The system was initially developed by Hydro and mainly used for oil and gas projects. The system provides a systematic approach to ensure a fast project completion. It is ensured that all equipment is available and checked at the time it is required. The system became a well recognized tool at Alunorte and helped to achieve fast commissioning and a start-up of the new lines without major delays.

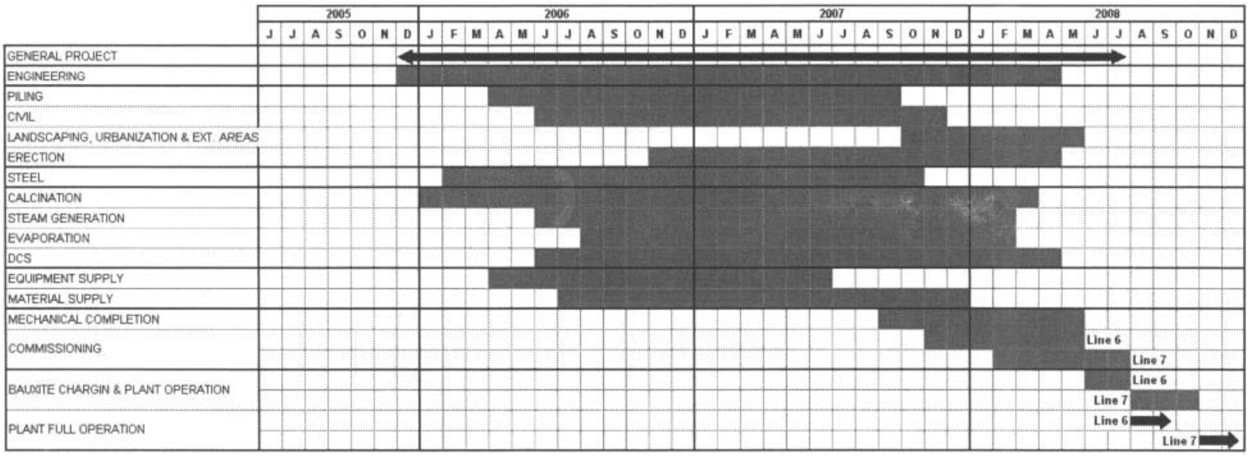


Figure 2. Project schedule of Expansion 3 project.

Alunorte's shareholders are very satisfied with the performance of the project organization, management and execution in general. An exception, however, is the unacceptable safety performance of Expansion 3. A fatality occurred during the construction caused by a crane fell on a passing construction worker. A TRI rate of 3.4 was reached for the overall Expansion 3 project.

Although the implementation of the process lines went according to schedule and the production capacity was achieved faster than initially planned there were some delays in the Expansion 3 project. Both the new boiler and the port expansion were delayed. The delays caused some operational challenges. Solutions were found to operate Alunorte at close to full capacity without having these projects finished. Expansion 3 included a high-pressure circulating fluidized bed boiler for steam and electrical power generation. As the boiler was delayed the required steam for the new process lines was provided by already existing low pressure boilers. For more than one year Alunorte had to operate without spare boilers. Delays in the early phase of the port expansion could not be recovered so that finally the installation of a new alumina shiploader could not be finished on time. Therefore some logistic challenges needed to be overcome at the port. The situation was challenging but Alunorte succeeded to ship alumina at a rhythm exceeding to 5 million t/yr with only one ship loader without loosing production due to logistical problems at the port.

### Start-up and Operational Performance

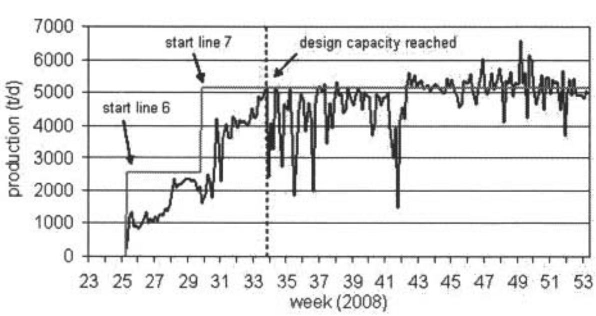


Figure 3. Ramp-up of Alunorte's lines 6 and 7.

The two new lines started up in sequence. In Figure 3 the alumina production from lines 6 and 7 is shown from start-up to the end of 2008. The nominal production capacity of both lines was reached within two months after start-up of the first line. The work on the coarse seed and fine seed filtration units was not finished when the lines started operation. Therefore it took somewhat longer to reach the nominal plant capacity. During Expansion 2 it was demonstrated that it is possible to achieve full production in 20 days for line 4 and 12 days for line 5.

With Expansion 3 new personnel was contracted by Alunorte. The hiring started enough time before the planned start-up of the new lines. Training for the new operators started about a year before commissioning. In this way it was possible to perform the start-up of the new lines with a team of sufficient experience.

Overall, the new lines performed as expected. No major negative surprises were experienced when the lines were started up. Although a new precipitation concept was installed for which no operational experience existed no major problems turned up. Lines 6 and 7 are fully based on Paragominas bauxite and some minor differences in process behavior were observed caused by the bauxite. These differences were mostly found in the clarification area. The fine particle size distribution of the bauxite might be the cause of a somewhat slower settling mud as compared to Trombetas bauxite. Measures were taken to correct the situation in the clarification area.

The energy utilization of Alunorte is among the best in the world with about 8 GJ per ton of alumina. As there are few plants with a similarly low energy utilization this defines the world-wide benchmark for alumina production. A detailed review of Alunorte's energy efficiency is presented in [6]. Alunorte's specific caustic consumption is mainly determined by the non-controllable losses which are driven by the content of reactive silica in the bauxite. Controllable losses are small with less than 8 kg per ton alumina. Although the content of reactive silica is somewhat high in both bauxites, Trombetas and Paragominas, their quality is generally very good. The content of available alumina is high and the content of organic material very low. In combination this leads to a low specific consumption of bauxite and very clean liquor with low concentrations of impurities. This

Table I. Typical alumina quality parameters of Alunorte.

| | | | |
|---|---|---|---|
| $SiO_2$ | 0.015 % | α-alumina | 5.0 % |
| $Fe_2O_3$ | 0.015 % | LOI (300-1000 °C) | 0.8 % |
| $TiO_2$ | 0.005 % | LOI (110-300 °C) | 0.7 % |
| $Na_2O$ | 0.4 % | BET | 75 $m^2$ |
| ZnO | 0.001 % | + 149 µm (+100#) | 3.0 % |
| CaO | 0.01 % | + 74 µm (+200#) | 70.0 % |
| $V_2O_5$ | 0.002 % | - 44 µm (-325#) | 7.0 % |
| MnO | 0.001 % | app. density | 0.97 g/cm3 |
| $P_2O_5$ | 0.001 % | attrition index | 17 % |

is an important driver for the high precipitation productivity which is achieved by Alunorte. With Expansion 3 and the productivity could be even improved.

The use of a higher fraction of Paragominas bauxite, the process modifications implemented and in particular the implementation of a new precipitation concept did not result in a negative impact on alumina quality to achieve a higher process performance. The alumina produced by Alunorte is one of the preferred qualities of Hydro's Norwegian smelters. With the start-up of lines 6 and 7 the previous alumina quality characteristics could be maintained. However, some minor differences can be observed when the product from lines 6 and 7 is compared to that of the older lines. The content of occluded soda is slightly higher and the lines are operated with slightly coarser crystal size distribution in precipitation. No difference is observed for Attrition Index. The product of the new lines is blended with the product of the other lines before shipped or sent to the nearby Albras smelter. In Table I the typical alumina quality parameters of Alunorte are shown. As result of improvements done in lines 6 and 7 compared to the older lines variations in alumina quality parameters became smaller. As the variations in all lines are generally small and the product of all lines is blended this effect is not observed in the final product, in particular not for alumina which is shipped. The storage in silos at Alunorte, transport by ship and storage at the smelters lead to additional homogenization of the product. However, the target is to operate the process as stable as possible in order to achieve the best possible performance.

## Project Budget

The project cost of Expansion 3 was 629 USD per annual ton of alumina. The project budget was set up in both currencies US Dollar and Brasilian Real (BRL). The project budget was met in BRL but there was a budget overrun in US Dollar. The main cause was the development of the Brasilian currency during the project. At the beginning of the project the exchange rate was 2.2 while it dropped to about 1.6 at the end of the project. In Fig. 4 the development of the Brasilian Real in comparison to the US Dollar is shown for the period from 2000 until the end of 2008. The situation of Expansion 3 is compared to the Expansions 1 and 2. A large amount of the material and equipments was purchased in Brasil so that project cost in BRL were not significantly affected by the development of the currencies.

Expansion 3 was finished close to the beginning of the world-wide economic downturn end of 2008. The additional alumina volume from Expansion 3 was added to the market at a time of falling LME and alumina prices. The sudden development of the alumina market made clear how important it is to operate a plant

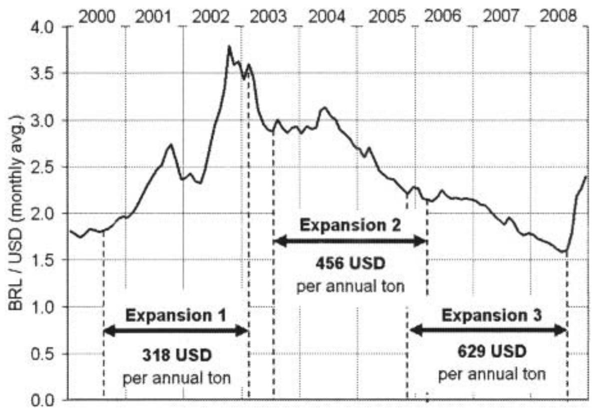

Figure 4. Project cost in relation to development of Brasilian Real.

with good performance and low specific consumption figures. Alunorte's operational performance is generally good with low specific energy utilization and controllable soda loss.

## Management of a 6.3 Mtpa Alumina Refinery

Alunorte has grown as fast as no other alumina refinery before and has a size which exceeds the second-largest alumina refinery by about 50 %. In this way Alunorte stands out in comparison to all other alumina refineries in the world. In the following section a critical review is presented about Alunorte's current performance, actual challenges and expected development in the coming years.

### Safety

There is a high focus on safety at Alunorte. The YTD TRI rate in October 2010 was 1.95 (based on one million working hour), after having achieved a TRI rate of 2.37 in 2009. Alunorte has developed and continuously improved a strategy to manage health and safety during the past 15 years of operation [7]. Alunorte is ambitious to further improve this performance in the coming years. The decision to install new technologies at Alunorte always includes some new risks for accidents which need to be carefully addressed.

### Process & Technology

The general technical performance of Alunorte is described above. Operation is characterized by a high productivity, low controllable caustic consumption, low energy utilization, a state-of-the art bauxite residue disposal concept and low plant emissions.

For good plant performance and good product quality it is important to operate the refinery as stable as possible. Operational variations must be kept small and the degree of non-planned maintenance must be kept as small as possible. One of the challenges to achieve a good performance in these aspects is the fact that Alunorte can be considered as one huge alumina production complex which can be divided into three major units. The first unit are lines 1/2/3, the second lines 4/5 and the third 6/7. Since the equipment installed in these units is not identical and different process concepts exist, e.g. in precipitation, specific operation and maintenance procedures are required. The three units are with small exceptions process-wise fully independent from each other. The plant liquor of one unit is usually not mixed with liquor of another unit so that individual characteristics for each of the units exist. One example was given above. The settling behavior of Paragominas bauxite is different from that of Trombetas. The advantage of the separation of the lines is that operational disturbances of the process in one line do usually not affect the other lines. Even a stop of a line is possible without affecting the production of the lines in the other operational units.

The three production units are, however, not fully independent from each other. They share utilities such as the electrical system, steam generators, bauxite supply and port. Operational problems in one of these plant areas can affect the whole process and will in this case lead to significant losses in production. Alunorte recognized that this is a risk for the operation of the whole refinery and started a program to minimize the interconnections between the units as far as possible. This task became more and more important as the plant grew. The complexity of the plant increases exponentially with its size and the possibilities for equipment failure which can affect larger parts of the plant get bigger. The availability of the plant is exposed in a similar way. The more complex the refinery got the more efforts were required to maintain a high global availability.

Logistics are another important issue. Some of the challenges arose from the delay of the port expansion. This issue could be handled as described above. However, the tonnages of alumina, bauxite, caustic and boiler fuels are huge and require a careful planning of port operations. Unsatisfactory performance in this part of the plant could result in an increase of transport and handling cost or in the worst case in production losses. A similar challenge exists for the transport of bauxite residue to the residue disposal area (RDA). It is transported by trucks from the filtration area to the disposal area. In case of bad weather conditions as it can frequently happen during the rainy season from December to April the disposal to the RDA can become a bottle neck. As the plant has the potential to creep in production in the coming years and the bauxite quality slowly deteriorates the amount of bauxite residue which needs to be disposed will increase in the future and the challenge will gets bigger. Alunorte studies options to improve this situation in order to improve the logistics and also eliminate a potential safety risk caused by the large number of trucks in service. In addition to logistics of materials, transport logistics for Alunorte's employees needs to be mentioned as well. Alunorte is located at about 40 km from Belém, the capital of the state Pará, in straight line. The road, however, is much longer – about 100 km. Many of Alunorte's employees live in Belém and travel forth and back day by day. To improve the situation Alunorte launches a ferry connection between the plant and Belém city.

After many years with a high focus on growth Alunorte has entered into a phase of optimizing the operation of the plant. There is potential for some increase in production. Furthermore, Alunorte works constantly to improve energy utilization and specific consumption figures. Some counteracting factors have to be considered such as the aging of the equipment or a slow deterioration of the bauxite quality in the long-term perspective. As part of the current work on process optimization new technologies are reviewed and tested to guarantee good operational performance also in the long term.

Organization & Management

In early days when Alunorte consisted of two lines only 450 people were employed. Nowadays, Alunorte employs 1,600 people and about 1100 more workers as permanent contractors. Due to the very fast growth of the plant Alunorte's team is very young and many of the employees have only few years of work experience. The plant has not only grown very fast but also new technologies were employed. The dewatering of the bauxite received through the pipeline from MBP is a new technology not only for Alunorte but also for the whole alumina industry. Alunorte could not profit from the experience of other alumina refineries. The first circulating fluidized bed boilers were installed as part of Expansion 2. Although the technology is not new as such it was new for Alunorte. Furthermore, there is just a small number of circulating fluidized bed boilers installed in South America. Both, the young organization and the application of new technologies at Alunorte result in a strong demand for training for operators and engineers.

As explained above the plant consists of seven lines which can be divided into three units consisting of lines 1/2/3, 4/5 and 6/7. The operational issues are not the same in the different lines. In some plant areas, such as precipitation, different process concepts are chosen. Furthermore, the first lines have an age of 15 years while the newest lines are just two years old. All this has to be considered in daily operation, for maintenance, training of the employees, etc. The principal management organization of Alunorte is still very similar to that in place during the early years of operation. It can be questioned if today's organization is still ideal or if other concepts are more suitable. Alunorte works actively to evaluate the current issues and challenges to manage the plant. Alunorte's is generally open to new ideas, technologies and concepts and works also on a continuous improvement of the plant organization.

## Conclusion

With Expansion 3 Alunorte has become the largest alumina refinery in the world with a production capacity of close to 6.3 Mtpa. Alunorte has grown as fast as no other refinery in the world. The development of Alunorte from its start-up in 1995 is presented and Expansion 3 is reviewed in detail. The design of Expansion 3 is based on that of the previous lines. However, a number of new technologies are applied, such as a new precipitation concept, different filters for pregnant liquor or the use of deep thickeners only for mud wash. The Expansion 3 project had a duration of 32 month with a short start-up phase of two month for both new lines to reach design production capacity. The project cost of Expansion 3 was USD 629 per annual ton of alumina. The installation of the two new process lines could be performed on schedule and on budget. The generally good performance of Alunorte, such as energy efficiency or alumina quality parameters, could be maintained also after the addition of the two new lines. The challenges of managing a plant of the size of Alunorte with a young team with on average few years of work experience are discussed. Alunorte has not only grown very fast but has implemented a number of new technologies, such as bauxite transport as slurry in a pipeline or the installation of CFB boilers. Training of Alunorte's operators and engineers is therefore important. Nowadays, Alunorte can be considered as a big alumina production complex with seven process lines which can be divided into three units, namely Lines 1/2/3, 4/5 and 6/7.

This offers technologically and organizationally possibilities to operate the units independently of each other with the aim to achieve a high global availability of the plant and to minimize the risk of failures in one line affecting the rest of the refinery. Alunorte has the goal to further improve the operational performance of the plant in order stay among the best plants in the world also in the long term.

## References


1. 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.

2. 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.

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

4. Michael Missalla, Jan Jarzembowski, Roger Bligh, Hans Werner Schmidt, "Increased Availability and Optimization of Calciner Performance due to Automation", *Light Metals 2009*, Bearne, G., Ed., TMS (The Minerals, Metals & Materials Society).

5. 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).

6. Reiner Wischnewski, Cleto Maues de Azevedo Jr, Emerson L.S. Moraes, Arthur Barros Monteiro, "Alunorte Global Energy Efficiency", In *Light Metals 2011*, Lindsay, S., Ed., TMS (The Minerals, Metals & Materials Society).

7. Jorge Aldi Dias Lima, "Safety Performance at Alunorte", In *Light Metals 2008*, DeYoung, D.H., Ed., TMS (The Minerals, Metals & Materials Society), 5-11.