ENERGY CONSUMPTION IN THE BAYER PROCESS

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Abstract

In the Bayer process, cost pressures associated with fuel consumption for steam generation and gibbsite calcination has led to an increased focus on efficient energy use and recovery. Additionally, with the Clean Energy Bill passing through the the Australian Parliament, the focus on greenhouse gas emissions associated with fossil fuel combustion in Australia, is further driving the need for energy reduction initiatives. Whilst significant improvements have occurred, further energy reduction opportunities are required to continue to meet community and business expectations, and to move the optimum energy cost closer to fundamental and technical limits.

This paper details a systematic approach to cataloguing energy flows and losses throughout the Bayer Process, and details methods for identifying further energy reduction initiatives. This approach has assisted the identification of energy efficiency opportunities in Rio Tinto Alcan's existing operations, and provides a foundation for the development of a sub 6GJ/t Alumina Refinery flow sheet for a future Greenfield refinery.

1. Introduction

According to the International Aluminium Institute (IAI), the average total energy consumption of their constituent refineries is 11.2 GJ/t (Online IAI accessed 11 November, 2010), with Low Temperature Refineries consuming between 9 to 11 GJ/t and High Temperature Refineries consuming between 9 to 14 GJ/t (Mahadevan, 2009). At these levels, IAI constituents consume in excess of 600 PJ of energy

per annum, which is greater than the combined domestic energy requirements of both Australia and New Zealand, with an energy consumption of 20 GJ per annum per capita (Online ABS accessed 11 November, 2010).

Furthermore, according to the International Energy Agency, both coal and natural gas (the key energy sources for many refineries) have seen significant increases in cost. Worldwide coal prices have increased from approximately USD 20/t in 2000 to USD 100/t in 2010, whilst natural gas prices have increased from approximately USD 3/MBtu in 2000 to USD 8/MBtu in 2010 (Online IEA accessed 11 November 2010). These cost pressures have driven energy to become the most significant cost to Refinery operations (Henrickson, 2010).

Hence, due to both the significant energy consumption of Bayer Process Refineries and escalating energy costs, the importance of on-going energy improvement initiatives in existing refineries and the development of low energy consuming greenfield refineries is a business and environmental objective.

2. Theoretical Energy Limitations in in the Bayer Process

Several papers have been written detailing the fundamental limits of energy consumption in the Bayer Process.

The thermodynamic minimum energy requirements for the dissolution of gibbsite and boehmite have been estimated as follows (Songquing et al. 2007):

Gibbsite: $Al(OH)_3 + OH^- \rightarrow Al(OH)_4^-$ where:

$\Delta H_{298K} = 0.66$ GJ/t Al_2O_3

Boehmite: $AlOOH + OH^- + H_2O \rightarrow Al(OH)_4^-$ where:

$\Delta H_{298K} = 0.44$ GJ/t Al_2O_3

Whereas the thermodynamic minimum energy requirement for the precipitation of gibbsite is the reverse of the above reaction.

As there is no net chemical or temperature change for the combined reactions, the thermodynamic minimum of the Bayer Process is virtually zero (Online DOE accessed 11 November 2011). However, from a more practical standpoint:

- As the energy recovered during precipitation is low grade, the minimum thermodynamic requirement can be considered to be ~ 0.6 GJ/t (Thomas 2010).

Furthermore, practically it is estimated that the:

- Minimum caustic liquor sensible heat requirements are ~ 1.5 GJ/t (Thomas 2010)
- Minimum evaporation requirements (if water ingress occurs) are ~ 0.5 GJ/t (Thomas 2010)

Hence it can be estimated that the total practical minimum energy requirement of Bayer Process is between 2.1 to 2.6 GJ/t, depending upon the amount of evaporation required.

The theoretical minimum energy requirements for the calcination of Gibbsite to form Alumina are given by its thermodynamic heat of reaction (Perander, L. M. et al. 2011) as follows:

Gibbsite: $Al_2O_3.3H_2O \rightarrow Al_2O_3 + 3H_2O$

$\Delta H_{298K} = 1.98$ GJ/t Al_2O_3

Hence, the theoretical minimum energy consumption for the production of Alumina via the Bayer process is ~ 4 GJ/t (not including electrical requirements for Bayer slurry transport and other process needs such as vacuum pumps and control equipment)

3. Bayer Energy Reduction Methodology

Due to the discrepancy between theoretical energy consumption and the actual energy consumption of Bayer Process Refineries, a systematic approach mapping energy consumption and identifying opportunities has been developed.

The approach can be broadly broken down into the following stages:

- The development of energy metrics to catalogue energy losses
- The identification energy loss pathways (convective, conductive etc.)

- The development of flow sheet options to minimise energy losses
- The modelling and validation of new and existing technology options for Greenfield Refineries and retrofits to existing Bayer Refineries.

3.1 Development of Energy Metrics

Worldwide, there are in excess of 70 Bayer Refineries (Online Wikipedia accessed 11 November 2010) which due to bauxite mineralogy, age of construction, number of expansions, cost profiles, technical providence etc. have very different flow sheets and operating conditions. As a result, the identification of energy reduction opportunities is often challenging and complex.

In order address this, a "standard" Bayer Process flow diagram was developed which incorporates all major process and energy flows within Bayer Process Refinery Areas that have an enthalpy greater than 0.5 GJ/t. These streams were then used to conduct mass and energy balances across defined Bayer Process Areas in order to calculate the net energy loss of each area.

Consideration was given to the selection of the boundary limits of each Bayer Process Area, so that mass and energy balances to closed irrespective of various flow sheet configurations and process conditions, so that a direct comparison of energy loss could be made between Refineries.

Hence for example, by selecting the following inputs and outputs into the Precipitation area all Bayer flow sheets became directly comparable:

- Pregnant Liquor stream (Filtered Digestion Slurry)
- Secondary Dilution stream (Mud Washer Overflow)
- Seed (Coarse and Fine Seed)
- Return Filtrate and Miscellaneous Dilution streams (Product Washing)
- Pump Off Slurry (Hydrate Slurry)

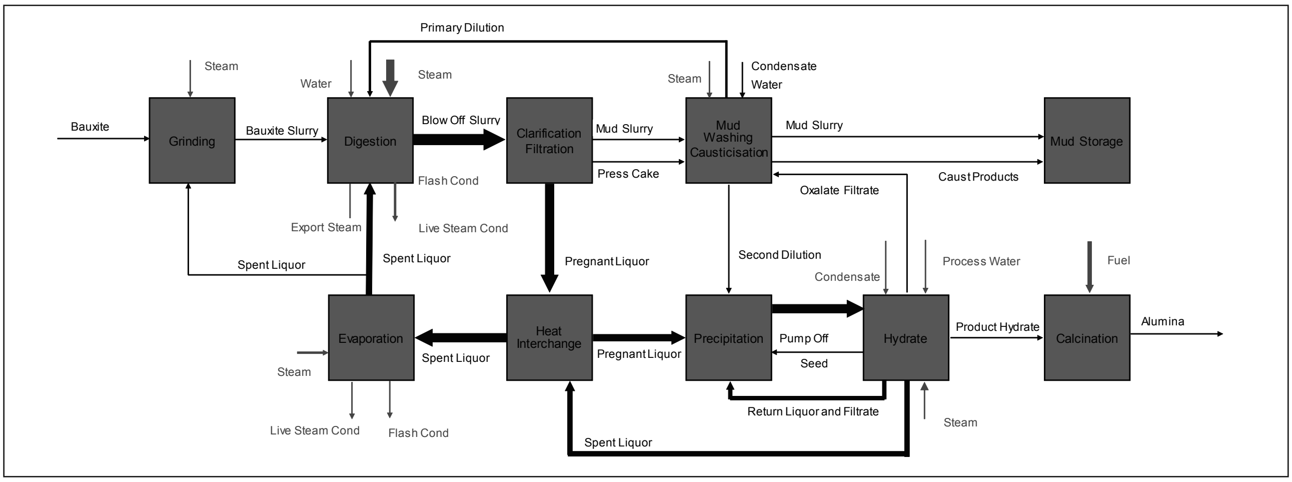
Once defined, real world data was obtained from laboratory samples and online instrumentation for each of inputs and outputs, such as:

- Soluble caustic
- Soluble alumina
- Solids concentration
- Volumetric flow rate
- Temperature

This allowed for the calculation of real-time mass and energy balances, which under steady state conditions typically closed to less than ±5%.

Enthalpy balances were then calculated with the data to determine the total energy lost in each area. Each enthalpy balance excluded the enthalpy associated with the heat of reaction, and the energy loss was normalised with production rate to give a total GJ/t energy loss metric.

The flow chart below shows the key process streams that were considered for each Bayer Process Area mass and energy balance.



Using this approach, various refineries with different flow arrangements, technologies, chemistry, and process conditions were able to be directly compared. This allowed for the identification of technologies and flow sheets that were more or less energy efficient.

3.2 Identification of Energy Loss Pathways

Typically in a Bayer Refinery, energy is lost by one or more of the following pathways:

- Ambient (radiation, convection, conduction)
- Motive (fluid flow)
- Waste (steam loss)
- Exhaust (combustion product loss)
- Reject (cooling tower)
- Process Requirement (water ingress)
- Mixing (raw material input)

Once the primary GJ/t metric for energy loss was calculated for each Bayer Process Area, the result was then further categorised into one or more of the energy loss pathways.

Hence for the key energy loss areas, the following shows the further categorisation of energy loss into the energy loss pathways:

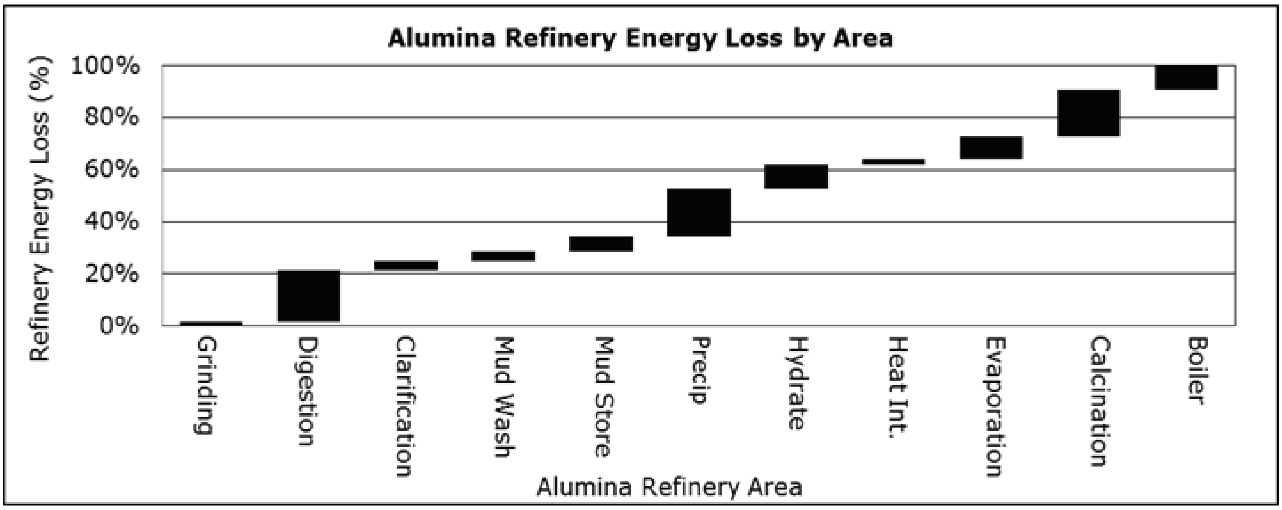
Digestion, where key energy losses are ambient (~50% due to hot pipework and vessels) and waste (~50% due to Blow Off Steam losses)

Precipitation, where key energy losses are reject (~40% due to cooling tower use) and ambient (~60% due to radiation, convection and conduction losses from Precipitation tanks)

Evaporation, where key energy losses are Process (due to the amount of ingress water evaporation required) and Rejection (~90% due to cooling tower use)

- Calcination and Boiler House, were key energy losses are Exhaust (~80% due to combustion gas discharge).

The graph below shows the total energy lost in a refinery by Process Area. All energy lost is ultimately replenished with live steam from the boiler house, raw fuel to the calcination area or import electricity.



Using this approach, it is possible to narrow down both the key focus Bayer Process Areas for the recovery or minimisation of energy losses, as well as the pathway by which energy is lost, which then forms the basis for energy improvements in further flow sheet developments.

3.3 Development Flow Sheet Options to Minimise Energy Losses

Flow Sheet development makes use of the philosophy that a reduction in energy losses from the Bayer Process, results in a reduction in energy input required by the Bayer process.

This is achieved in three stages:

- A pinch analysis is conducted to identify simple heat recovery options between process streams.
- Energy efficient technology options, which were evaluated in the development of energy metrics, are then incorporated into the flow sheet.
- Further novel energy recovery measures, which were evaluated in the identification of energy loss pathways, are investigated and incorporated into the flow sheet.

More specifically, the investigation of novel energy recovery measures uses a targeted, systematic approach to identify energy saving opportunities. Hence:

- Ambient heat losses, occur when ambient air temperatures are less than the wall temperatures, allowing heat to be transferred to the ambient air via convection, conduction and radiation. Key focus areas are lagging of hot pipework and vessels, reflective coatings, as well as the design size of vessels.
- Motive losses, occur as Bayer Process Fluids are transported, agitated or mixed. Key focus areas include electrical efficiency of pumps and motors that are in operation, as well as plant layout and operating conditions.
- Waste energy losses, are unwanted losses by the release of steam or Bayer process fluids to the external environment. These leakages include steam losses via steam traps and Digestion relief systems, evaporation from open tanks as well as condensate discharge from the Boiler House. Key focus areas are the prevention of Digestion Blow Off Steam, Condensate discharge as well as waste Bayer Process fluids which is released to catchment areas.
- Exhaust losses, are gaseous losses to the atmosphere which are the result of combustion products in Calcination and in the Boiler House. Key focus areas are the efficient use of economisers, heat recovery systems for preheating of Bayer process streams and the recovery of this heat back into the process.
- Rejection losses, are the desired removal of excess heat from the process, via equipment such as water cooling towers. Key focus areas include evaporation and precipitation operating conditions, and whilst these losses are essential to maximise production, the recovery of energy from these represents a significant opportunity.
- Process energy losses, are energy losses associated with specific flow sheet requirements to maintain production levels in the Bayer Process such as water ingress or the method of organic carbon management. Key focus areas include the minimisation of water ingress, the minimisation of barometric evaporation and re-evaluation of process requirements which require additional heating.
- Mixing energy loses occur as cold raw material streams are added to hot Bayer process streams, which subsequently cool the Bayer slurry, and ultimately increase the energy requirement in Digestion. Key focus areas are the use of available heat sources to pre-heat raw material streams.

Using this approach, it is possible to develop novel flow sheet configurations, with best in class technology, that target the root cause of energy losses in the Bayer Process to reduce the requirement for live steam generation in the Boiler House and fuel consumption in the Calcination area.

3.4 Modelling and Validation of a Greenfield 6GJ/t Refinery flow sheet

The use of this methodology has allowed Rio Tinto Alcan to develop a refinery flow sheet which is able to operate at below 6 GJ/t total energy requirements. This includes:

Electricity (as electrical energy) at approximately 0.7 GJ/t

Steam generation (as thermal energy) at approximately 2.7 GJ/t

Calcination (as thermal energy) at approximately 2.5 GJ/t

The flow sheet is developed for Weipa Bauxite, as a high temperature refinery with appropriate organic management systems.

The flow sheet has been modelled via SysCAD, using Rio Tinto Alcan Bayer property model. From this, this model has undergone preliminary model reviews, where no significant underlying issues have been found which would reduce the processing ability of the 6GJ/t Refinery flow sheet. Furthermore, a technology review has also been conducted, where no significant mechanical issues have been found which would stop the operating ability of the 6GJ/t refinery flow sheet. It is believed that the technology required for the flow sheet is either already in operation or is in advanced stages of development.

4. Modelling and Validation of Brownfield Refinery Retrofits

Furthermore, the use of this methodology has allowed Rio Tinto Alcan to highlight several opportunities for energy improvements to their existing Alumina Refineries.

These retrofits are under development and validation using SysCAD modelling, which will allow for the calculation of a business case, and allow for a further reduction in the energy consumption of existing operations.

5. Conclusions

It has been shown that by minimising energy losses from the Bayer Process using a systematic approach to catalogue energy flows and identify further energy reduction initiatives, it is possible to develop a greenfield refinery and brownfield retrofit options to significantly reduce the energy consumption associated with Alumina production.

This will assist in reducing cost pressures associated with higher prices of energy used in steam generation and gibbsite calcination, and allow Rio Tinto Alcan to better meet community and business expectations with respect to energy management.

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