7. WATER, EVAPORATION, AND ENERGY

Water is required by the process to recover the chemical values in the process solution associated with the disposal of bauxite residue. Part of this water enters the process and is subsequently removed by various process liquor evaporation facilities. There are other sources of input water, but the water for bauxite residue washing is the largest. The precise control of process liquor concentrations, resulting from a balance of water dilution and process liquor evaporation, is complex.

Wastewater management is the term used to control water associated with bauxite residue disposal for environmental purposes.

Closely related to water management and evaporation is the overall energy efficiency of the alumina refinery. Four papers are included that deal with refinery energy efficiency. Theoretical energy usage is largely associated with the quality of bauxite used, the control of scale deposits in heat transfer facilities, the temperature required for digestion, and the energy used by the calcination equipment. With an increase in energy costs, plant design changes are available for cost/benefit evaluation in new or existing Bayer processing plants as a trade off between energy savings and higher capital equipment investment.

Fred Williams

ALUMINA REFINERY WASTEWATER MANAGEMENT: WHEN ZERO DISCHARGE JUST ISN'T FEASIBLE....

Lucy Martin[1] and Steven Howard[1]
[1]Bechtel Australia, 100 Brookes Street, Brisbane, Queensland 4006, Australia

Keywords: "Alumina Refinery, Waste water, Environmental Design Criteria"

Abstract

Management and treatment of liquid effluents are determinant considerations in the design of alumina refineries. Rainfall, evaporation rate, proximity to the coast, process design and layout, ore mineralogy, the local environment, and potential impact on contiguous communities are all integral to the development of an appropriate refinery water management strategy. The goal is to achieve zero discharge of liquid effluent to the environment. However this is not always the most feasible solution under the extreme rainfall conditions in tropical and subtropical locations. This paper will explore the following issues for both inland and coastal refineries:

- Methods to reduce and control refinery discharges
- Treatment design criteria
- Socioeconomic aspects relating to surface water use in settlements adjacent to the refinery

Introduction

With an increased global focus on sustainable development from governments, international financing institutions, mining companies, and communities, new and expanding mining operations can face a higher level of environmental and sociological regulation and scrutiny than in the past. Many legislative frameworks allow existing operations to continue to meet a less stringent standard than would be expected on a greenfield facility. Therefore this paper will pay most attention to those regions expected to become future alumina sources and the associated technical barriers to sustainable and viable projects.

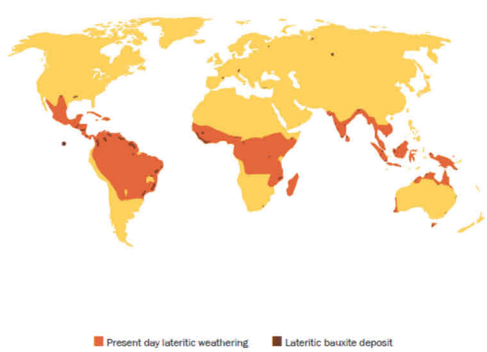

Figure 1. Lateritic Bauxite Sources (modified from Freyssinet et al [1])

The relationship of a refinery location to its bauxite deposit and transport infrastructure directly affects material handling equipment costs and resultant project NPV. The optimum location of the refinery will be strongly influenced by the investment required for materials transportation. Project NPV will in turn be impacted by the operating costs associated with that location. As commodity prices increase and accessible deposits become depleted, the need to develop inland ore bodies, and consequently refineries, is increasing.

Bauxite is formed through weathering of lateritic rock under high rainfall in tropical and subtropical environments. Figure 1 shows regions currently undergoing lateritic weathering. These regions tend to have well defined wet and dry seasons, which forces refinery designers to address the "feast or famine" issue associated with water availability. Zero discharge of effluent is ideal for sustainability, but is often impractical for water impoundment.

Bauxite also contains organic and inorganic impurities which increase the costs and environmental risks associated with its processing into alumina. This is primarily due to the solubility of the various minerals and organic compounds in the Bayer process liquor, and the tendency of the impurities to accumulate therein. Demonstrated treatment methodologies for the large scale effluent neutralization required for discharge into surface or marine waters primarily involve the use of either seawater alone, or seawater supplemented by spent sulfuric acid, a byproduct of the refining process. When considering refineries close-coupled to inland bauxite deposits, the cost of pumping seawater must be set against the cost of bauxite and alumina transportation.

In summary, this indicates that:

1. Water availability for refinery consumption will be highly variable from season to season
2. Water discharge will be required during both "extreme" or "normal" rainfall events.
3. In inland locations, water effluents may discharge into streams potentially used for drinking and primary industries (farming, animal husbandry, and fishing)
4. Typical refinery waste water treatment techniques, such as seawater neutralization, may not be feasible.

Refinery Water Balance

<u>Water supply and demand</u>

An alumina refinery that utilizes the Bayer process will consume 2.0-2.3 tonnes of raw water per tonne of alumina produced. The actual rate will depend upon the bauxite quality, the process design, demand for nonprocess applications (e.g, for potable water), and the extent water is recycled within the facility. About 10 percent of the total intake is accounted for by free moisture in the bauxite feed, and in the 50 percent caustic soda solution, the primary process reagent.

Figure 2 depicts the inputs and outputs of water across the outer system boundary between the refinery, including the residue disposal area, and the external environment. This assumes one hundred percent diversion of potential 'run-on' to the site.

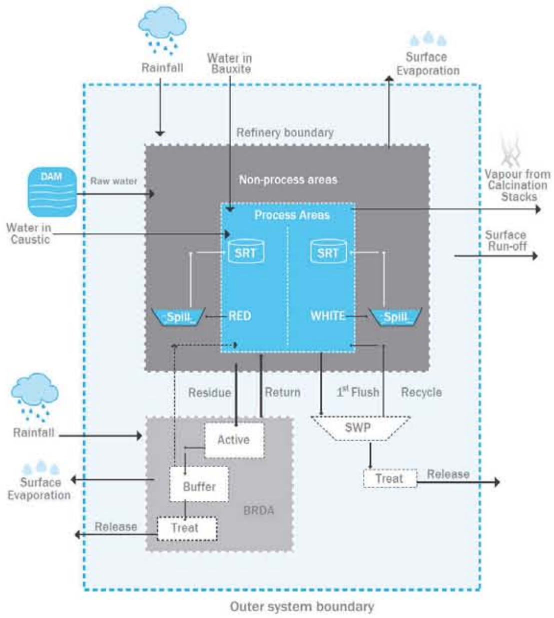

Figure 2 Refinery Water Balance

There are only two sources of water that supply the remaining ninety percent of the total demand: raw water from natural surface and subsurface sources, and rainfall. This means that a significant proportion of the water intake is *noncontrollable,* and under certain circumstances may far exceed the capability of the refinery to control the quantities involved.

With the notable exceptions of the People's Republic of China (PRC) and Russia, most refineries have been established in tropical and subtropical regions, in close proximity to the principal lateritic bauxite provinces. These are not only exposed to high seasonal rainfall, but are also at risk of extreme and unpredictable flood events. New capacity planned for Brazil, Guinea, and SE Asia will be faced with the same issues.

Environmental control requirements

It has long been recognized that effective environmental management is critical to the viability of any project. Stringent environmental control standards and industry best practice with regard to operations and maintenance must be reflected in the refinery design criteria.

The focus of this paper is the management of liquid effluent, any release, either treated or untreated, of which is potentially harmful to the environment and consequently deleterious to the wellbeing of the community. The Bayer plant itself handles a large volume of process liquor, the bulk of which is an aqueous solution of caustic soda containing dissolved aluminium, silica, and many other organic and inorganic impurities, including trace metals such as Molybdenum and Vanadium, which occur in the bauxite.

The refinery is designed to contain the live liquor inventory, with minor spills within operating facilities being promptly returned into the process. Provision is also made to intercept larger, accidental spillages which could result from equipment failure or abnormal events, such as the loss of electrical power. Spill ponds are installed at strategic locations, and have sufficient capacity to handle the contents of one or more of the largest tanks in the various facilities. These measures minimize the probability of releasing highly concentrated, potentially toxic material which can only be discharged under the most extreme circumstances.

Environmental control measures for an alumina refinery must also include facilities to handle contaminated runoff, due to rainfall catchment within the facility perimeter. One or more stormwater ponds (SWPs) would also be provided, and must be considerably larger than the process spill ponds. An SWP is intended to impound rainfall runoff collected from *nonprocess areas,* which will mobilize relatively minor amounts of surface contaminants during the initial onset of rain. After a short period, typically about one hour, the runoff quality is similar to that found in neighbouring areas outside the refinery perimeter. The impounded SWP water is impure, but is suitable for recycling into the process for various duties, reducing the intake of raw water. Finally, the impoundment area constructed for the permanent storage of bauxite residue and other solid wastes, the bauxite residue disposal area (BRDA), also accumulates contaminated water, which may be returned to the process in order to recover the soda content.

Under normal operating conditions, the Bayer plant liquor inventory is controlled within narrow limits by varying the input rates of caustic soda, raw water and in-plant evaporation. Operating procedures should be aimed at keeping the process spill ponds empty, and the water levels in the SWP and BRDA as low as possible, during periods of little or no rain. The onset of heavy and/or sustained rainfall, typical in tropical locations, gives rise to large volumes of site runoff, and potentially run-on if this is not effectively diverted. This can rapidly fill the available impoundments, which have a finite limit despite the risk analysis and major investment involved in their provision. In order to handle situations that exceed the maximum impoundment capacity, the regulatory option often exists to impound only the so-called "first flush" runoff, after which all subsequent catchment would be allowed to bypass the SWPs and be released to the environment.

Exceptional rainfall events would defeat even this strategy (assuming that it were permissible) and the refinery would then be forced to release contaminated water to the environment. Such a release may be diluted to mitigate the alkalinity of the effluent, but would still result in contaminating receiving waters above background levels, probably in violation of licence provisions.

Community demand, including agriculture, for water may become a significant component of total consumption. Any shortage or degradation of the community supply may become a significant issue. These factors need to be considered in the overall conceptual design of the water supply system.

The conclusion is that despite careful scenario planning and investment in major infrastructure, sooner or later an extreme event will cause an unacceptable environmental incident. Therefore, the location of the refinery must be such that the receiving waters are able to withstand the impact in a sustainable manner. This explains why most major refineries are located near the ocean, which also facilitates the application of seawater neutralization, the only current demonstrably effective liquid effluent treatment technology.

Refinery design principles

The unavoidable accumulation of contaminated water due to rainfall, reclamation constraints, and severe limitations on release to the environment have the following consequences for the design of the refinery:

1. **Refinery environmental policy that mandates compliance with relevant regulatory standards becomes a major driver for selection of the refinery and BRDA locations**.

This policy also has a profound impact on refinery design features and the operational procedures that enable the standards to be met.

A policy mandating compliance with liquid effluent standards is consistent with that for particulate emissions or any other form of environmental impact. The difference between implementation for particulates (e.g., the installation of dust collectors) and that for release of impounded water is one of relative complexity for the latter and requires coordination of the total refinery design.

Facility design criteria must address the (water) environmental policy, ranked among safety and NPV considerations, and evaluate this before detailed design can proceed. Some objectives may be compatible, for example minimizing the caustic content of final stage mud washer underflow results in a significant reduction in operating cost.

2. **Departures from conventional refinery and waste impoundment design become necessary, and can add to the mitigation costs of potential effluent management problems.**

A refinery location that will experience extreme rainfall events should incorporate features to minimize both the volume effects and possible contamination of rainfall catchment. This facilitates the segregation of concentrated process liquor (that cannot be released) from relatively innocuous nonprocess runoff that can be impounded, recycled during dry periods, and released subject to meeting licence conditions.

Waste impoundment design must satisfy all of the following criteria:

- Effective, permanent sequestration of red mud waste that will continue to generate alkaline leachate over the longer term
- Recovery of supernatant liquor and impoundment drainage back into the refinery process.
- Sequestration of solid-phase organic and inorganic waste from process liquor purification facilities
- Disposal of other environmentally sensitive wastes (e.g., ash, scale, and waste acid)

3. **Measures must be adopted to minimize the controllable intake of raw water, particularly during the wet season, thereby reducing the total inventory to be managed.**

Due to the probable excess of rainfall over evaporation in the regions under discussion, raw water intake must be strictly controlled to minimize the total volume under management. It follows that the consumption of raw water in the Bayer process should be minimized by using as much water as possible that is already within the outer system boundary.

Raw water is needed for a number of essential process duties, treated for domestic (potable) water, and for the fire control infrastructure. The number of water entry points into the refinery must be minimised, and all volumes accurately metered. Strong design discipline is necessary to ensure consistent water control policies and practices are enforced. Some measures may conflict with custom and practice employed elsewhere, but capital and operating costs associated with treatment of this water may be excessive. For example, using hoses for housekeeping in process areas is perceived to improve employee safety by minimizing the hazard of caustic liquor exposure, but this may be achieved by proper safety procedures and training, whilst minimizing water usage.

4. **Introduction of measures to enforce economic use of *controllable* process and domestic water can significantly reduce usage.**

Water consumption may be allocated to two broad categories: *noncontrollable*, governed by the combined requirements for essential services, and *controllable,* which allows for some degree of flexibility as to the quantity used.

Most of the process requirements fall into the noncontrollable category, for example, boiler feedwater, flocculant, and lime preparation. All are examples of end uses directly related to the refinery production rate and to the demand for raw materials and additives. Domestic water demand is closely related to the number of employees. Effective control depends upon the installation of water saving devices such as tap restrictors, employee education regarding conservation, and the prohibition of usage for non-domestic purposes.

The final disposition of water usage in this category is important in limiting the potential environmental impact. Applications such as dust mitigation can help to dispose of excess impounded catchment under dry season conditions. Others, such as vehicle washing, may create additional problems caused by runoff turbidity or contamination by hydrocarbons and other chemical agents.

The supply of water to end users beyond the outer system boundary should be from an independent source of supply. This measure imposes a physical constraint on consumption and avoids uncontrolled influence on the infrastructure provided for the refinery itself.

5. **Several tiers of impoundments must be established to segregate process liquor, contaminated effluent and rainfall catchment.**

- Process spill containment

A "process spill" is defined as any form of liquor, slurry, or solids released during routine operational tasks within the plot limit of any facility. Spills of this nature are normally of low quantity and are promptly collected and returned into the process. The concentrations of process chemicals are too high to permit release to the environment.

There is a possibility that large process spills may occur due to equipment failure, such as a pipeline rupture. The refinery design should incorporate *process only* spill ponds for the purpose of intercepting and returning material that may overtop the limited facility containment capacity. The contents of spill ponds cannot be released, and should be recycled to the refinery via large sump relay tanks (SRTs), which provide additional surge capacity and operational flexibility.

Process design modelling should incorporate provision for large process spills, to ensure total containment facilities and return rates into the process are adequate, and that defined events of this nature do not compromise the refinery's rated production and other key parameters.

- Runoff management

"Runoff" is defined as rainfall catchment from the refinery plot limit that must be monitored for contaminants and handled accordingly. Runoff falls into two categories:

- Catchment within process facility plot limits. This may be relatively dilute, but is still far too contaminated for release. It must be returned to the process via the SRT system, and will have negative impacts on the process and energy demand. These effects must also be considered for the refinery mass and energy balance. The impact must be minimized by reducing the process catchment footprint, i.e., by roofing large tanks and routing rainwater catchment to surface drains outside the facility plot limit.
- Catchment from nonprocess areas. Runoff will mobilize soluble contaminants such as oil, dust, and dirt, the concentrations of which may be appreciable depending upon such factors as paving and drainage design, control of fugitive dust from the refinery, and general housekeeping standards. Under tropical rainfall conditions, the initial (or "first-flush") nonprocess runoff will exhibit short term contaminant loadings that will be sampled and the flow directed to a large Storm Water Pond (SWP).

In practice, the volume of runoff from "average" rainfall intensity can be far greater than the SWP capacity, as costs to construct these facilities to collect the rainfall volumes experienced in tropical and sub-tropical locations can be prohibitive. This can mean that all but a small fraction of nonprocess runoff must be released, and the refinery must be designed with this in mind. The water diverted to the SWP will be reclaimed as "process water", diverted to the BRDA buffer zone, or (as a last resort) treated and released.

There is a tendency to work with "average" rainfall data that can be highly misleading, and could result in erroneous assumptions underlying the planning for the capacities of spill ponds, SRTs, the SWP, and the BRDA. A credible environmental control strategy should be based upon scenario planning for abnormal events, such as 1:100 year return rainfall events.

- BRDA design

The BRDA is one of only two impoundments from which low-level contaminated water may be released (the other being the SWP), provided that the regulatory and/or best environmental control practices can be addressed. It may be possible to optimize the total capital investment for the two impoundments by linking them, such that the BRDA provides the final and somewhat larger capacity for low level effluent.

The design of the BRDA must prevent contamination of impounded runoff outside the deposition areas for red mud and the other solid wastes that have special sequestration criteria. Liquor that is either released from the residue slurry or accumulates from rainfall directly onto the mud deposition area must be recycled to the refinery.

A buffer zone between the active solid waste deposition zones and the outer BRDA perimeter should be provided to allow for abnormal rainfall events that may temporarily exceed the active zone's capacity. This liquor, and any other leachate from other waste disposal areas, should not be allowed to mix with impounded low level water.

The remaining area of the BRDA may be used to store and reclaim, or to treat and release, excess water. The final treatment and disposition method will be site-specific, and will depend upon a number of factors (alkalinity, toxic ionic species, BOD, temperature and turbidity) associated with the effluent itself and the background conditions in the receiving waters.

- Final Stage Mud Washer Underflow Slurry

The residue slurry contains solid phase compounds that will release highly alkaline leachate over a long time frame due to unavoidable contact with supernatant liquor and rainfall. This tendency cannot be controlled at source, due to the presence of sodium aluminium silicates and calcium compounds formed in the Bayer process. The only control, at the margin, is to minimize the concentration and quantity of liquor disengaged from the residue, and to reduce direct contact of the consolidated mud with liquor or rainwater.

The major controllable variables for residue disposal are the density of the slurry, and the alkaline concentration of the liquor discharged with the slurry into the BRDA disposal area. Paste thickening is the most effective means of preparing very dense, immobile slurry which will release little or no liquid as it further consolidates under its own weight.

The remaining design issue is to minimize the final stage mud washer underflow total soda, usually measured as g/L Na_2CO_3. A typical target is 5 g/L, estimated from the number of washing stages to be installed, the ratio of wash water to mud, and other factors. The target is estimated by the *steady state* refinery mass balance, and by making certain assumptions related to equipment reliability, washer stage efficiency, etc. Under actual conditions, major departures from steady state operation and other assumptions cause excursions in last washer soda, by as much as a factor of 10, to 50 g/L or more. This implies that the number of installed washing stages and the sparing of pumps should go beyond that suggested by steady-state modelling; otherwise the environmental control objectives will be unachievable.

Discharge Criteria

Where bauxite mining and alumina refining are emerging, local and national legislation and associated compliance monitoring are often not sufficiently developed to address contaminants of interest associated with these activities. Consequently, drinking water, primary industries and ecosystems may not be adequately protected by the existing environmental legislative framework.

Many international mining and minerals processing companies have implemented sustainable development policies which require them to not only meet the requirements of in-country legislation, but to also consider the use of the best available technologies and international guidelines. For projects seeking external financing, the International Financing Corporation (IFC) has developed specific Environmental Health and Safety (ES&H) guidelines that are "technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)". These guidelines are used by the IFC for project appraisals. IFC EH&S guidelines have been developed for both mining and base metal smelting and refining [2,3]. However these may not include all contaminants of interest relevant to alumina refinery effluent discharge. For example, the base metal and smelting guidelines state that toxicity should be considered on "a case specific basis" and do not provide guidelines for discharge of heavy metals associated with alumina refining.

Assuming that local legislation is not sufficiently defined, guidelines from international organizations and other countries with highly developed legislative frameworks can also be used to develop robust design criteria for effluent discharges from the project site.

Design criteria for effluent disposal must consider the environment to which the effluent will be discharged – a primary consideration is whether the discharge is to fresh water or the marine environment. Discharge quality requirements to marine water are often less stringent than the discharge to fresh water due to various factors, including higher naturally occurring baseline concentrations of compounds in marine water compared to freshwater, increased dilution of effluent when discharged to open water, and less sensitive receptors from both an ecosystem and downstream user perspective in saline water.

Surface water is used for drinking, recreation, and primary industries in many countries. In developing countries it is more likely to be used for these purposes without treatment. Strict and enforced industrial zoning legislation is required where industrial effluent is discharged to control population influx and resultant water usage; however this is often lacking in the regions currently experiencing growth in bauxite mining and associated refining. In these situations it must be considered that human and animal ingestion of surface water could take place at any point outside of the industrial fenceline, therefore drinking water quality standards, as a minimum requirements, must be attained at inland refineries discharging to streams and rivers.

An alternative is to provide a separate secure drinking water supply to the local population and educate them regarding withdrawal of water, which may limit the treatment costs for effluents. If this can be achieved and is accepted by permitting authorities, then it may be possible to discharge at a higher concentration and allow for mixing until drinking water, or other international standards, are achieved at a compliance point downstream of the discharge location. Mixing zone calculations need to take into account the lowest surface water flowrate when calculating dilution, as this can often mean that discharge criteria to achieve compliance at a the edge of a mixing zone need to be more stringent during the dry season. This applies to impurity concentrations, temperature, and turbidity (visual impact)

Non-Governmental Organizations (NGOs) are an increasingly prominent force in the enforcement of environmental and sustainable development policies. There is an increasing public demand for independently verified information and action, due to the poor performance of some regulators and companies. Therefore, in countries without sufficient environmental legislation to protect the health of local communities, their livelihoods, and the surrounding flora and fauna, large corporations are often under pressure to implement stringent environmental and sustainable development policies to protect their reputation.

In summary, development of project specific effluent discharge criteria to meet sustainable development policies will require a vigorous social, health, and environmental impact assessment of existing and potential future uses, and a "one size fits all" solution cannot be applied. However, generally speaking, discharge quality requirements to marine rather than aquatic environment are less stringent and consequently more achievable.

Effluent Neutralization Technologies

In this context, the term neutralization refers to the reduction of the level of alkalinity in the stream to be treated. Neutralization processes are required for effluent that is to be permanently sequestered, or is to be released to the environment where there is no other alternative.

An alumina refinery will generate large volumes of liquid and solid phase alkaline effluent from a variety of sources, predominantly waste mud and other process byproducts discharged with the mud, including:

- Diluted process liquor entrained with the bauxite residue (red mud)
- Insoluble fraction of the bauxite (iron and titanium oxides)
- Desilication product (DSP) – hydrated sodium aluminium silicates
- Calcium compounds, e.g., tri-calcium aluminate, calcium oxalate.

The other effluent streams will be generated by contamination of rainfall runoff from the refinery site, and possible spillage and release of process materials to impoundments.

Effluent that is released from the waste mud stream will invariably exhibit pH levels above 12. Both the liquid and the solid phase sources of alkalinity (hydroxide ions) must be reacted with a neutralizing agent. The rate at which the neutralization reaction proceeds will vary greatly depending upon the reactants involved, the pH, concentration, and temperature.

Principles of Effluent Treatment

The primary objective is to reduce the immediate and longer term environmental risk of the (solid or liquid) waste stream by reducing the alkalinity to the minimum practicable level. However, low alkalinity is not the only consideration. Potentially serious soluble pollutants such as aluminium and other elements (e.g., molybdates, vanadates and arsenates) must also be targeted.

Options for neutralization include reaction with seawater, dilute sulfuric acid (or a combination of both), and carbon dioxide. A third option, carbonation, is in the early stages of development and little process performance data is available to suggest this as a viable option at this phase of development.

Application of either seawater or acid neutralization must recognize that a certain fraction of solid phase alkalinity is released over long periods of time, weeks or months, depending upon the prevailing conditions and the composition of the residue. In practical terms, there is no such thing as complete neutralization, due to the limited treatment time available.

Treatment with sulfuric acid invariably involves the utilization of spent dilute acid used for cleaning refinery heat exchangers. During the cleaning process, the acid dissolves scale deposits which may contain additional pollutants. A corrosion inhibitor will also be employed, the nature of which must be assessed if the reacted acid is to be released into the environment.

The chemical and physical properties of the particular bauxite to be processed have a determinant impact upon the process design of the Red Side of the refinery, upon the BRDA design, and upon the technology selected for effluent treatment. Significant effort and cost must be invested in the characterization of the bauxite, and the same attention must be paid to the environmental control requirements.

Basis of Design

The Refinery Basis of Design must specify the following fundamental criteria:

Refinery location. .

- Will it be practicable to utilize seawater neutralization?

Climatic conditions – rainfall and evaporation.

- Will it be necessary to release effluent to the environment, and what quantities are likely?

Receiving waters for effluent release.

- What are the social, agrarian and environmental factors associated with effluent release?
- What effluent discharge standards should apply?
- What are the critical parameters for the outfall point?

Waste streams to the BRDA

- What tonnages of solids and liquid waste are to be discharged?
- What will be the composition of the red mud?
- What variability in waste loadings and concentrations may be expected?
- What is the probable toxicity profile, and does mitigation technology exist?

Acid Neutralization

Residue is mixed with dilute acid which reacts immediately with soluble alkalinity, producing a rapid but temporary drop in pH. This is commonly achieved by adding (waste) acid after the last mud washing stage. Attack by residual acid (if any) on the solid phase alkaline content occurs over a much longer time frame, and may lead to a gradual increase in pH. It is therefore impractical to neutralize the solid phase component prior to residue disposal. Post-neutralization of waters released from the BRDA may be necessary.

Acid neutralization produces a dilute sodium sulphate solution, which, if released, may give rise to environmental impact in its own right, such as algal blooms or local concentrations exceeding background levels, or that specified for potable water (<250 mg/L).

Careful assessment must be made to establish that sufficient acid will be available for primary/secondary residue or effluent treatment, that probable peak effluent discharge rates can be handled, and potential heavy metal contamination of spent acid is acceptable.

Seawater Neutralization

The important reaction in seawater neutralization is the precipitation of hydroxyl ions by reaction with magnesium (Mg^{++}) ions present in the seawater. Again, the rate of reaction varies greatly – rapid in the liquor phase, much slower with calcium compounds and DSP. The presence of sulfate ions will inhibit the reaction with DSP.

A major advantage of seawater neutralization is the precipitation of aluminium ions during the formation of hydrotalcite, the primary reaction product from the soluble alkalis and magnesium. Hydrotalcite formation has also been shown to remove vanadium, molybdenum and phosphorus provided that the pH is in the range 8.0-10.0.

Seawater neutralization of residue allows immediate effluent discharge, provided turbidity criteria can be attained, eliminating the need for separate containment and management of liquor. By providing excess seawater, alkaline runoff generated by the slow dissolution of alkaline compounds can be neutralized and released.

System design must ensure that the seawater supply and discharge capacity always exceeds the magnesium demand of excursions in residue alkalinity, due to process problems. If the pH is allowed to rise, some of the trace metals in the hydrotalcite will revert to the soluble phase and impact on receiving water quality. If excess alkalinity cannot be precipitated within the BRDA, additional hydrotalcite precipitation will occur at the outfall, creating a visible plume.

It should be noted that attempts have been made to augment seawater neutralization with sulfuric acid. This significantly alters the chemistry such that a much lower pH is necessary to remove aluminium from the solution. Removal of oxalate is favoured at high pH values, so that the addition of acid may be counterproductive and costly.

Alternative Technologies

Other technologies for industrial water treatment, such as membrane treatment and ion exchange, are untested on alumina wastewater chemistry and at the scale discussed in this paper. If these technologies were proven to be effective, the volumes that would require treatment in tropical and sub-tropical locations would result in significant increases in capital and operating costs for these facilities.

Conclusion

In tropical and subtropical climates, coastal and inland refineries will discharge effluent under normal and extreme circumstances. To minimize the amount of effluent requiring treatment and discharge, the environmental design features and operational controls for management of raw water intake, and the water balance detailed in this paper should be incorporated into the alumina refinery design.

Inland refineries pose additional challenges due to the stringent discharge criteria applied to inland waterways. Discharge criteria can be imposed, such as government legislation or financial institution requirements, or prescribed by company internal sustainable development and environmental policies. In either circumstance, effluent discharge requirements are often defined according to the expected use of the water body by contiguous communities.

The most demonstrated treatment method for large scale refineries is seawater neutralization. Transport of seawater to an inland refinery and the reverse for discharge can put a strain on the project capital and operating costs, and may not be feasible.

Other water treatment methodologies are not proven on large scale refineries required to meet stringent inland water requirements and may require expensive reagents to treat the effluent. These can increase the risk profile of the project, drive up capital and operating costs and may result in breaching of discharge design criteria, with consequential downstream impacts.

Acknowledgements

Thanks to Bob McCulloch and Bill Imrie for their valuable comments and Rosemary Dotlic, Daniel Hayes & Eric Tlozek from the Bechtel Communications team for their assistance in formatting and editing this paper.

References

1. Ore-forming Processes Related to Lateritic Weathering; P.H Freyssinet, C.R.M Butt, R.C Morris and P. Piantone. Society of Economic Geologists Inc. Economic Geology 100th Anniversary Volume p681-722
2. IFC General Environmental, Health, and Safety Guidelines: Mining, December 10, 2007
3. IFC Environmental, Health, and Safety Guidelines Base Metal Smelting and Refining April 30, 2007