Freshwater Free Alumina Refinery

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Abstract

When designing future refineries, more sustainable outcomes that embrace circular economy principles must be incorporated. The reality of a net zero carbon world approaches, demanding net zero carbon refineries. Another key design criterion is the freshwater footprint. Fresh water is a precious resource, essential for life. Climate change will amplify its scarcity in many regions. A refinery that needs no fresh water would be of greater benefit for local communities, reducing environmental impact and risk as well as improving energy efficiency. In this paper a typical alumina refinery water balance is described, highlighting areas of opportunity. Potential technologies for reducing water footprint are assessed. Incorporating selected technologies into a single process model, a "freshwater free" design is proposed. Designing future refineries for a more sustainable world will require innovative thinking, development of technology and a lot of hard work to deliver robust solutions. These challenges, and a path forward, are discussed within the context of the "freshwater free" refinery.

Keywords: Bayer plant, Water balance and consumption, Seawater cooling, Mechanical vapor recompression (MVR), Alumina sustainability.

1. Introduction

The Bayer plant, used worldwide predominantly for production of smelter grade alumina from bauxite, is a hydrometallurgical process. In simple terms bauxite is treated with a caustic soda solution at elevated temperature and pressure to dissolve alumina. The dissolved alumina is then separated from the insoluble residue before being precipitated in a granular form suitable for smelting to aluminium. The following discussion assumes a typical modern alumina refinery of two parallel trains of 1.0 million tonne/year capacity each.

As the Bayer plant is a hydrometallurgical process, a large amount of water is used in the process. The liquor stream in the process is recirculating around the refinery, constantly being loaded with alumina in the digestion area and then stripped of alumina in the precipitation area. The spent liquor stream generated in the precipitation area is concentrated by evaporation and returned to the digestion area. In this way caustic soda is reused and caustic consumption kept to an economically viable level. There is a varying degree of recycle and reuse of water streams in a Bayer plant refinery, often driven by the need to limit freshwater input, conserve energy and to limit water losses to the environment. Minimization of freshwater usage has become increasingly important in terms of sustainability of the alumina industry, particularly for site locations where freshwater is scarce. It is also critically important for drought situation which can sometimes put strong pressure on the refinery (see Pei et al [1]).

The overall water balance for the entire facility required to produce alumina can be divided into eight elements. The interaction of these elements numbered from 1 to 8 is typically shown in Figure 1.

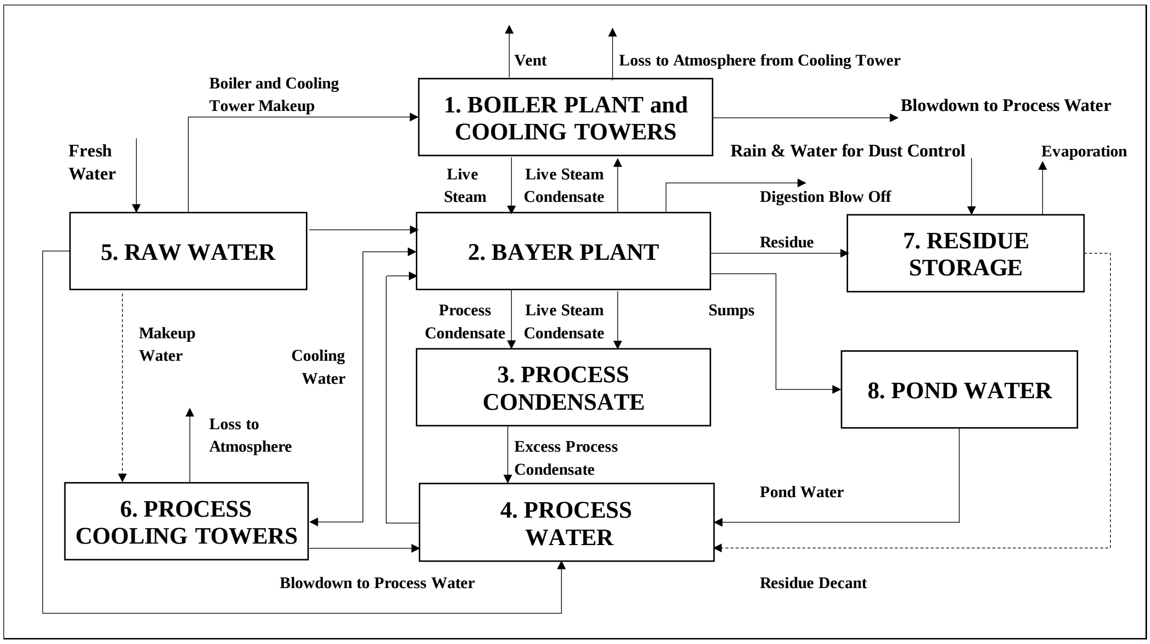


Figure 1. Overall water balance.

Most Bayer plants use bauxite containing predominantly Gibbsite (aluminium tri-hydrate) that can be readily digested at relatively low temperatures in the range of 140 to 170°C. For the bauxite containing an appreciable amount of Boehmite (aluminium monohydrate), digestion at high temperatures in the range of 230 to 280°C is required to improve the refinery economics.

In terms of the water balance, the major difference between high and low temperature Bayer plants is in the proportion of evaporation that occurs in digestion and evaporation areas. Because of the high temperature in digestion, more water is evaporated in more than three flash stages, so the demand for additional evaporation downstream is reduced comparing to low temperature digestion.

As condensate can potentially be contaminated with slurry or caustic in the process, it must be properly controlled and classified according to the conductivity level. Some of the usages will require good quality condensate, for example, process condensate for product washing and high purity live steam condensate as boiler feed water.

A process simulation model has been developed in this study to represent the overall water balance towards achieving zero freshwater consumption. Several potential technologies are discussed for possible water reductions.

Whilst this paper will focus on the water balance of low temperature Bayer plant, some comments on the effect of proposed changes to reduce water consumption in high temperature plant will also be made where applicable.

The aim of the paper is to highlight the most feasible technologies for freshwater reduction, yet including some potential, but less feasible or not yet matured technologies, for further reductions. Evaluation of capital cost, operation cost, and technology risk has been intentionally excluded.

2. Elements of the Overall Water Balance

The overall water balance involves the interaction of many parts of the Bayer plant and its utilities. The main elements of the overall balance and their interactions are described below.

2.1 Boiler Plant and Cooling Tower

Dissolution of alumina into solution is done at elevated temperature and pressure, so an alumina refinery typically requires significant quantities of steam to operate as well as electricity.

A typical low temperature refinery considered in this paper uses a cogeneration facility to produce high pressure steam. Some high pressure (HP) steam is used to generate electricity for the refinery and associated facilities, and the remainder is bled off to provide high and low pressure (LP) steam for the refinery. A low temperature refinery generally uses only indirect steam heating of the digestion slurry with conventional shell and tube heat exchangers. The indirect steam heating does not generally add water to the Bayer plant during slurry heating, but the refinery does require makeup water due to steam losses, condensate losses and boiler water purge

In a high temperature refinery, whilst indirect heating is possible, the final heating of digestion slurry is often done with direct steam injection, depending on the age of the refinery, chemical scaling concerns and the technology available at the time. This results in additional water input to the slurry, and this will increase the load requirement to the evaporation process if the same digester caustic concentration is targeted.

The boiler plant for steam generation also requires a heat sink, which is inevitably a forced draft cooling tower, which requires makeup water to replace water lost by evaporation and blowdown.

The boiler plant also requires freshwater as boiler feedwater makeup to compensate for boiler blowdown losses. In the alumina refinery, good quality live steam condensate is recycled and makes up a significant part of the boiler feed water.

Figure 2. shows the key inputs and outputs for the water balance in the boiler plant.

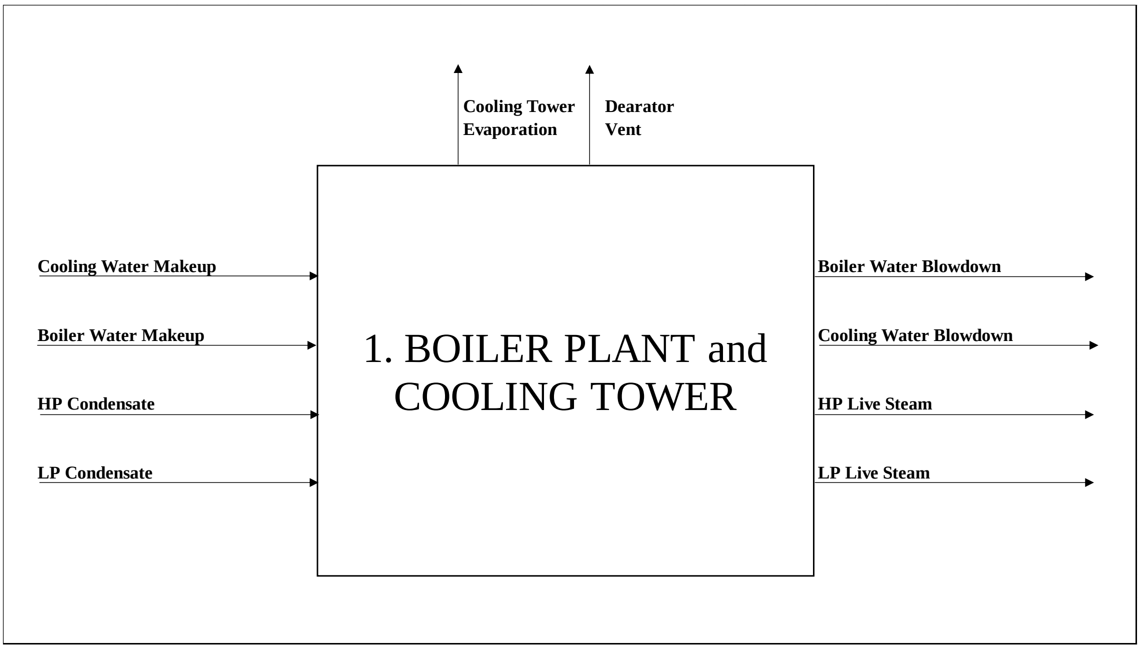


Figure 2. Boiler plant water balance.

2.2 Bayer Plant

The core of this investigation is the Bayer plant water balance. A simple water balance for the Bayer plant is shown in Figure 3. The scope of this water balance is the liquor circuit of the Bayer plant. The Bayer plant water balance does not include the cooling towers or boiler plant water systems.

The main inputs of water to the Bayer plant liquor are generally fixed in relation to the production rate and bauxite qualities.

The free moisture in bauxite inputs is specific to the bauxite being processed and its handling process. It normally varies only between tight limits, though significant moisture may be found for some bauxites in the rainy season. The chemical water input is generally determined by the production rate and bauxite properties, such as contents of Gibbsite, Boehmite, Goethite and reactive silica.

Water with caustic input is also relatively fixed with production rate and the raw caustic concentration, typically 48-50% caustic soda as NaOH. The fixed caustic consumption rate per tonne of bauxite treated is dependent on the amount and type of silica minerals present in the bauxite and the digestion temperature applied, as well as the bound soda content in product hydrate. The soluble soda losses are related to red mud washing and impurity control, as well as the leachable soda in product hydrate.

Direct steam input is rarely used in modern refineries. If direct steam input is used, elimination of it is an economic opportunity in energy efficiency more so than water consumption.

Other water input is associated with pump gland seal water and instrument purge water, small amount with concentrated acids and flocculant, as well as potential rainwater collected in the refinery, such as into open tanks and process sumps in bunded areas.

Makeup water to the process for mud washing is a result of the Bayer plant water balance. Minimizing this makeup water is one of the keys to reducing water consumption in the refinery.

Some of the main outputs of water from the Bayer plant liquor stream are also fixed in relation to production rate.

Product alumina hydrate chemical water is fixed with production rate by the molar ratio of H_2O to Al_2O_3 as 3. For low temperature plants, the hydrate chemical water is in balance with water input from the extracted Gibbsite. But for high temperature plants, the water input from the extracted Boehmite is less than the water lost to hydrate.

Product alumina hydrate free moisture is also generally fixed with production rate, varying from 5 to 8% moisture depending on the product filtration and washing technology applied.

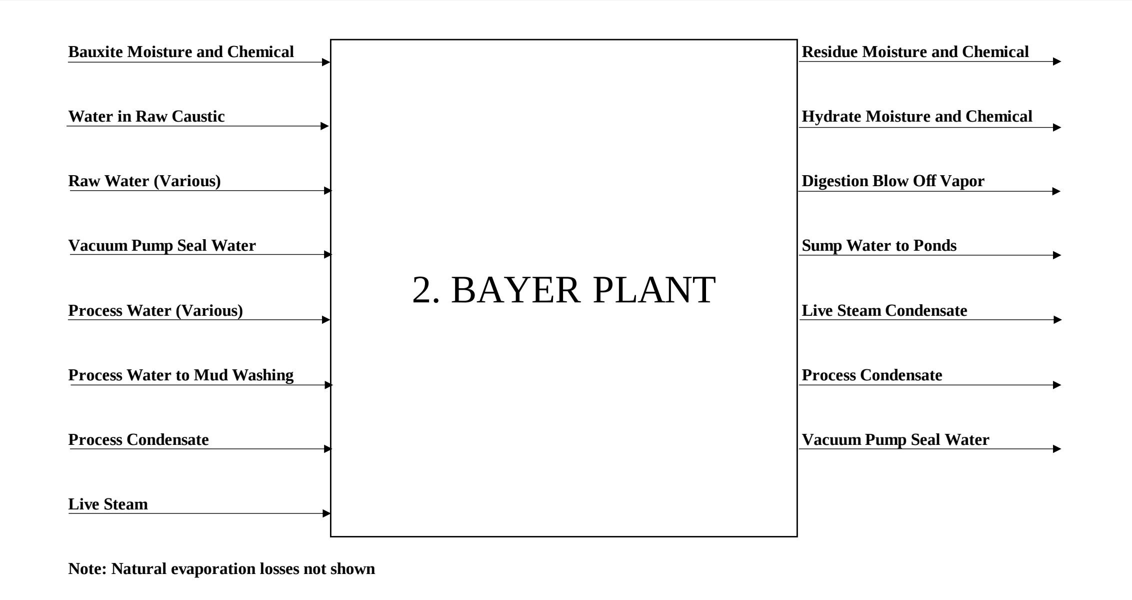
Hydrate chemical water and free moisture make up a significant water output stream, which is all lost to the atmosphere during calcination. Application of an alternative alumina calcination technology in the future could potentially recover this water partly or in whole (see section 4.2.4.).

A residual of vapor within the digestion process is lost from the blow off (BOF) vessel to atmosphere at ambient pressure. The BOF vapor emission rate can potentially be higher than ideal scenario if the performance of the digestion heat recovery process underperforms. Recovery of the BOF vapor by some means may potentially generate a pure water stream to replace some freshwater input.

The bauxite residue chemical water output varies with the production rate, alumina extraction rate, bauxite quality such as reactive silica, and by the chemistry of the process. Generally, the residue chemical water is mainly related to desilication product and in rough balance to water input from reactive silica (one molar ratio of SiO_2 to H_2O), though there is a small amount of losses with quartz attack at high temperature digestion.

Residue moisture depends on the technology employed for mud disposal, with the current trend towards residue filtration and dry stacking in newly built refineries significantly reducing the magnitude of this loss. Reduced moisture loss due to implementing red mud filtration means there is reduced removal of impurities together with soluble soda unless the soda concentration of the moisture is raised.

Another small loss of chemical water is associated with filter aid (tri-calcium aluminate $3CaO·Al_2O_3·6H_2O$) production used for security filtration. Filter aid is generally disposed together with red mud.



Note: Natural evaporation losses not shown

Figure 3. Bayer plant water balance.

To minimize freshwater input and maximize reuse of water generated or collected by the process there is a complex recycle and re-use of water commonly in all Bayer plants. The volume of tanks available for surge storage of liquor in a Bayer plant is small in comparison to the total volume. Therefore, the water input and output must be kept in balance to prevent tanks from overflowing or running dry. As there are several high-volume water users in the Bayer plant, recycle of various water streams is critical to minimizing freshwater input to the process. Also, the quality of water varies for each user, for example, product washing requires pure water, but mud washing can tolerate less pure water.

A key component of the water recycle in the Bayer plant is the process condensate system, and this is discussed in the next section.

2.3 Process Condensate

Within the Bayer plant there is a separate but highly interdependent water balance that is the process condensate system.

In modern refineries, there is often no direct steam input. The input of live steam is generally in balance with the live steam condensate, which is normally recycled as the boiler feed water. An imbalance can occur if part of the live steam condensate is contaminated. An allowance is usually provided for this in the design. The contaminated live steam condensate would be directed to the process water system.

Process condensate is produced in the digestion area as heat is recovered from the digested slurry stream, and in the evaporation area, and in heat interchange if flash cooling is adopted.

Process condensate is used for many purposes in the refinery. In the situation where condensate from digestion and evaporation is not contaminated, good condensate is supplied to all condensate users. Where one or more of the condensate producers is producing contaminated condensate, good condensate is supplied to the highest priority users. A typical good condensate user priority list shown below:

- Product hydrate washing
- Gland water
- Cleaning condensate to precipitation, classification and seed filters
- Condensate for makeup water to precipitation and evaporation cooling towers
- Lime plant water supply for lime slaking

The use of condensate for cooling tower makeup water is possible where excess good condensate is available. It can replace freshwater input to the cooling towers. In the situation where good condensate is in limited supply, fresh water can be used for the total cooling tower makeup demand.

Most refineries have two or three “grades” of process condensate, based on conductivity measurements. A typical condensate grading is:

Good process condensate:	0 to 150 µS/cm
Medium process condensate:	150 to 300 µS/cm
Bad condensate:	greater than 300 µS/cm

Bad condensate, in the above example can be greater than 300 µS/cm, or it can be just good or medium condensate excess to plant requirements. Bad condensate is then normally used for red mud residue washing, to recover caustic soda. Depending on the amount of condensate produced, user requirements and red mud wash factor, there may be an excess or deficit of condensate. In the example considered here the deficit is made up with process water. The interaction between the condensate balance and the red mud washing area is shown in Figure 4 with bad process condensate going to mud washing.

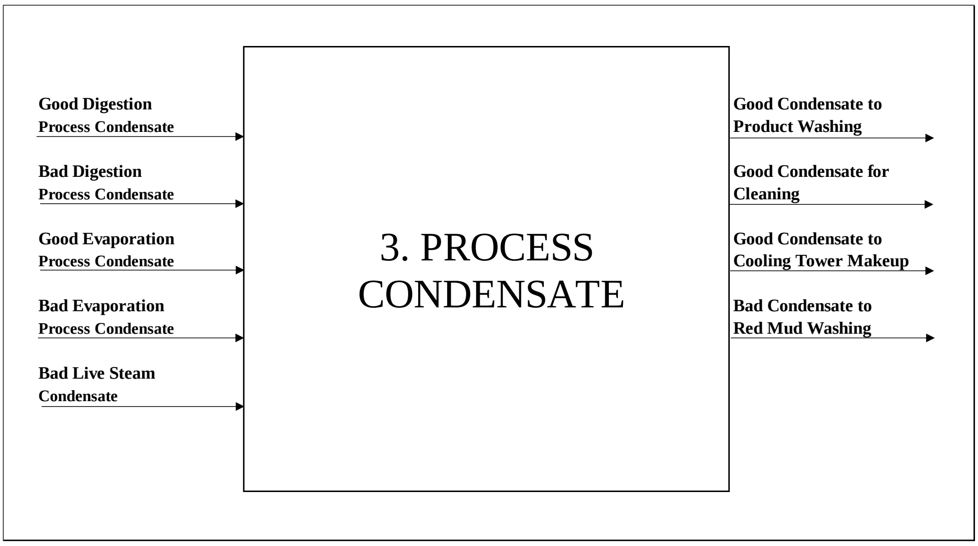


Figure 4. Process condensate balance.

For a 2 million tonne/year refinery two or three multiple effect evaporator units typically provide sufficient evaporation capacity. Where the evaporation plant operates with a barometric condenser as the final condensing stage, there is an impact on the Bayer plant water balance.

Vapor from the barometric flash stages is absorbed by cooling water and sent to a cooling tower. This becomes a de facto cooling water makeup stream. But when it contains caustic contamination, the result is increased blowdown of cooling water, which is a loss of water from the condensate / freshwater system.

2.4 Process Water

Process water is the term used to define a water system that is used for many general purposes in an alumina refinery. In some refineries process water is relatively clean, in others it is combined with red mud filtrate or decant liquor/rainwater from the red mud dam and therefore contains some level of caustic soda and other impurities.

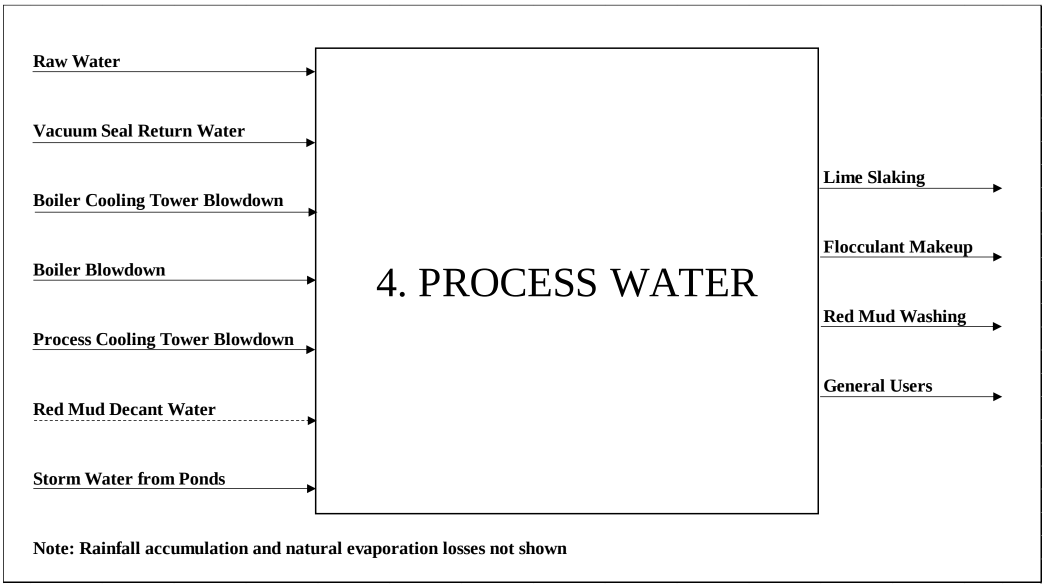


Figure 5. Process water balance.

2.5 Raw Water

Raw water input to the refinery can be provided from bores, rivers or municipal water supply. Raw water may be used directly for users requiring relatively clean water or added to the process water stream. In the case considered here, raw water is used both directly and added to the process water stream (Figure 6.).

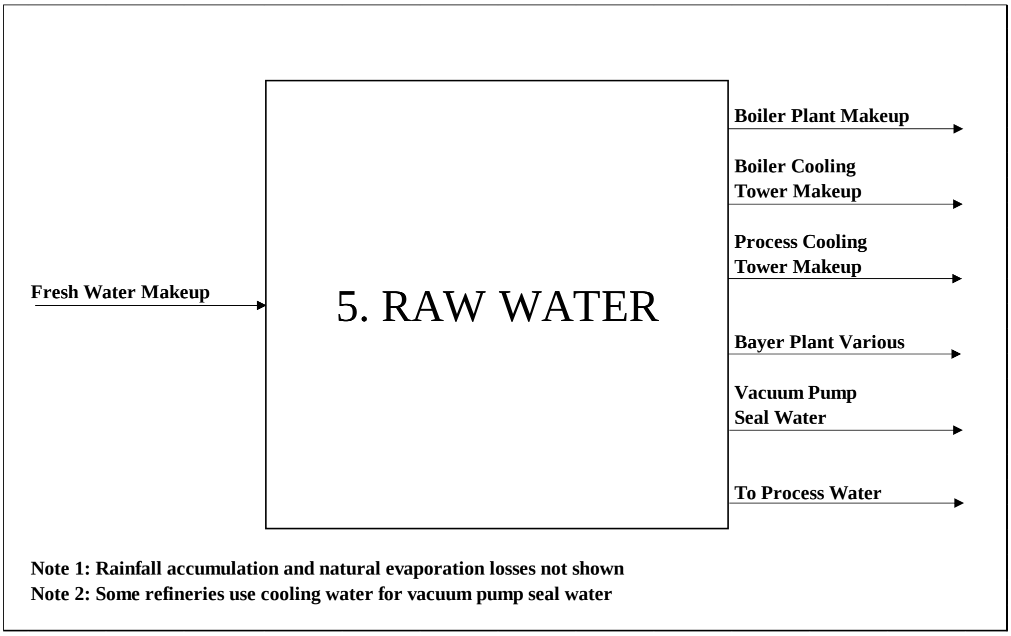


Figure 6. Raw water balance.

2.6 Process Cooling Towers

The digestion of alumina takes place at elevated temperature and pressure. After separation of bauxite residue and removal of residual solids in the liquor by security filtration, precipitation of alumina trihydrate occurs at temperature in the range of 70 to 50°C. A major portion of the cooling is achieved by flash cooling or indirect cooling of pregnant liquor with spent liquor from 106°C down to about 70 or 80°C before being added to the precipitation tanks.

Precipitation occurs in a series of mechanically agitated tanks with gravity overflow between tanks. To increase the productivity of the precipitation process, the slurry is cooled in several steps using technologies such as flash cooling, shell and tube or wide-gap plate heat exchangers with the heat rejected predominantly to cooling water. Final precipitation pump-off slurry temperature is generally in the range of 50 to 60°C to meet the requirements of both production and product qualities. In alumina refinery terms this is the lowest grade heat in the liquor circuit, and not suitable for heating any other process streams.

After precipitation and classification, the product alumina trihydrate is filtered and washed. Washing with clean condensate is most common.

Water from hydrate washing, mud washing, cleaning and maintenance activities results in dilution of the process liquor. The liquor stream is re-concentrated by an evaporation process. This is commonly done in one or more trains of multiple effect evaporators, with the final effect driven by water cooled barometric condensers, so cooling water is also required in the evaporation plant.

The final process step requiring cooling water is in the calcination area. Alumina trihydrate is calcined to alumina at temperatures close to 1000°C. Modern alumina calciners recover heat counter-currently in several stages, but the final product is still too hot for conveying directly by conventional means. Fluid bed coolers are employed to cool the hot alumina with cooling water.

Given the large process flows, the heat rejected to cooling water is significant in the refinery. Several cooling towers are therefore required in different process steps to reject the absorbed heat to atmosphere, so that the cooling water can be reused. See section 3 for more details.

The water lost to atmosphere in the process cooling towers is not directly replaced with raw water, because the base case model uses excess good condensate for this purpose. If this excess of good condensate is not available, it would have to be replaced with raw water. If the excess condensate is contaminated, it would still be replaced with raw water, but it would in turn reduce raw water input to red mud washing (via the process water circuit).

The water balance for the process cooling towers is similar for different process steps. An example is represented in Figure 7.

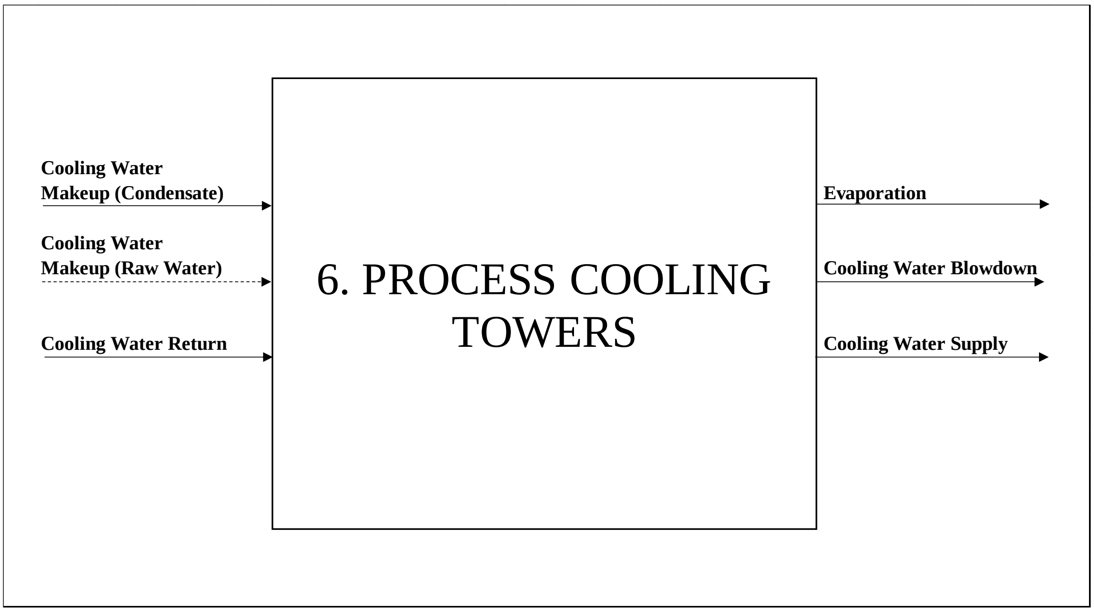


Figure 7. Water balance in process cooling towers.

2.7 Residue Storage

Mud filtration and dry stacking are standard technologies in modern refineries. Where the storage site is located remote from filtration facilities, dry mud cake is trucked from the filtration discharge to the storage site. There will then be no decant water return to process. Any water collected on site may replace the spray water required for dust control, partly or wholly depending on actual local rainfalls.

In refineries where the storage site is nearby, dry mud cake is trucked from the filtration discharge to the storage site, but decant water may be returned to process water, depending on actual rain falls. This is particularly important for locations where the storage sites need to deal with significant rainwater collections. Figure 8. shows the water balance in residue storage area.

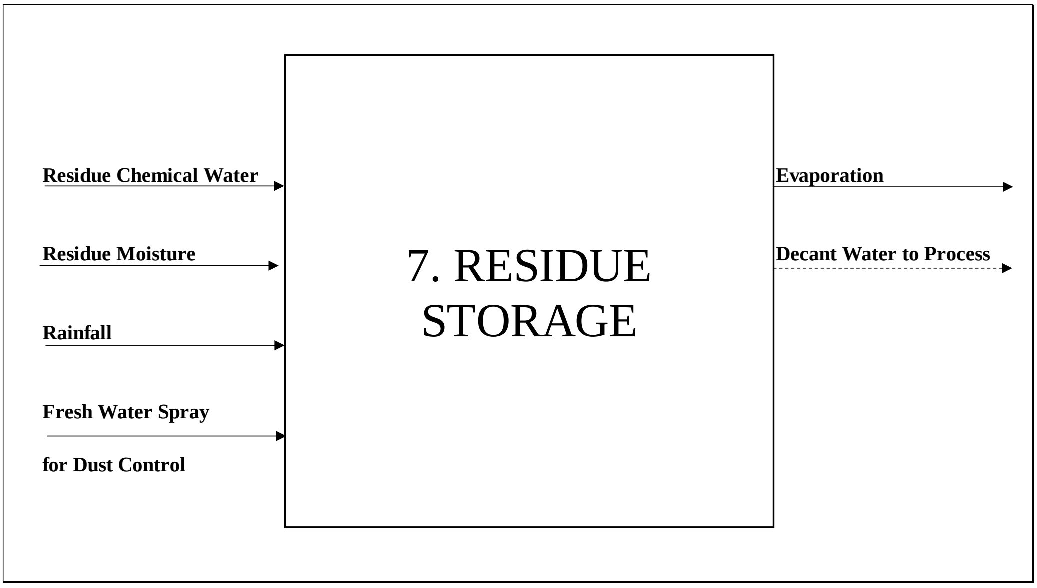


Figure 8. Residue storage water balance.

2.8 Storm Pond Water

In the water balance example considered in this paper, storm water from refinery site is collected in ponds by use of refinery sumps and recovered for use in the refinery (Figure 9.). Inputs to the ponds are direct rainfall and sumps from the refinery area (when they contain rainwater only). This water is recovered into the process water system described in section 2.4. The amount of water available for transfer to process water is highly dependent on rainfall in the case considered.

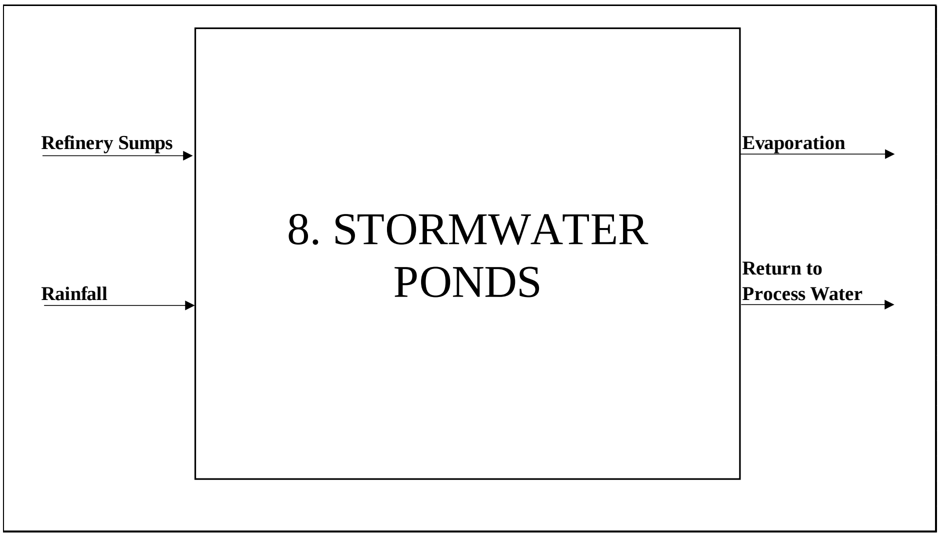


Figure 9. Stormwater pond balance.

3. Typical Unit Water Consumptions (Base Case Refinery)

The next step in investigating of how to reduce freshwater consumption to zero is to consider the output of the process modelling of the base case. The generic base case refinery is defined as:

- Cogen power plant to provide both steam and power to the refinery giving this is the more efficient technology choice.
- Two parallel digestion trains, each of 1 million tonne/year alumina production.

- Low temperature digestion using typical Gibbsitic bauxites with typical reactive silica content, and 50% fresh caustic to supplement the caustic losses.
- Digestion BOF vapor is vented to atmosphere.
- No direct steam injection heating (indirect slurry heating in both predesilication and digestion).
- Conventional high-density red mud settlers and washers.
- Residue filtration for dry stacking with moisture lost to residue cake.
- Conventional multiple effect evaporators with most of the live steam condensate returned to boiler plant.
- Freshwater cooling towers (one in each of the areas: boiler plant, precipitation, evaporation, calcination, respectively).
    - Cooling tower makeup is provided by vacuum pump seal water and good condensate.
- Water blowdowns in boiler plant and cooling towers are recycled for mud washing.
- Conventional fluid bed calciner technology with both hydrate moisture and chemical water lost to atmosphere.
- The generic base case refinery is located in a climate where the rainfall is insignificant and can be neglected.

Table 1 below shows the breakdown of the specific water consumption by users. The specific water consumption, defined as tonnes of raw water input per tonne of alumina produced, for the base case refinery it is indicatively 2.40 t/t.

Table 1. Base case specific water consumptions.

Main water users (Raw water)	**Next level water users breakdown**	**Main user specific consumption (t/t)**	**Comment**
Boiler Water Makeup		1.07	
	Deaerator Vent		The sum of next level usages is about equal to the makeup to boiler plant.
	Blowdown		
	Steam Usage in Boiler Plant		
	Cooling Tower Evaporation		
	Live Steam to Process		
General Refinery Input (Various)		0.13	Potable water and hose water etc. – lost to either disposal or evaporation.
Vacuum Pump Seal Water		0.26	Vacuum pump seal water is collected into the refinery system.
Process Water		0.94	Balance of raw water required for process water.
	Lime Slaking		The sum of next level usages is about equal to the makeup to process water.
	Floc Makeup		
	Red Mud Washing		
Total		**2.40**	

The base case has an excess of good condensate available for red mud washing and for process cooling tower makeup. Because condensate is used for process cooling tower makeup, it does not show up as raw water consumer. It does still present an opportunity for reducing raw water consumption. For example, if seawater cooling is implemented, this condensate can be redirected to red mud washing duty, therefore reducing raw water input to the process water system.

Table 2. lists the evaporation losses to atmosphere from various cooling towers in the refinery. The total loss is 1.75 t/t for the base case refinery. If the BOF losses is added, the total will be 1.90 t/t water losses to atmosphere.

Table 2. Cooling water lost to atmosphere.

Process areas	**Water lost to atmosphere (t/h)**	**Specific water loss (t/t)**
Precipitation Cooling Tower	177	0.60
Evaporation Cooling Tower	130	0.44
Calcination Cooling Tower	36	0.12
Boiler Plant Cooling Tower	174	0.59
Total Cooling Tower Losses	**517**	**1.75**
Digestion BOF Losses	44	0.15

4. Potential Technologies to Reduce Freshwater Consumption

The following are technology categories in which potential improvement may be realized:

- Category I – Reduce the water inputs that subsequently need to be removed from the system
- Category II – Reduce Water Losses from the Refinery
- Category III – Minimize live steam consumptions and subsequently reducing the boiler water makeup

Category I is not a focus of this paper due to the following reasons:

- The water input from raw materials are essentially fixed, and significant reductions in this regard are unlikely.
- Steam direct injection into the refinery has been eliminated in the base case.
- Rainfall impact has been excluded. In high rainfall regions good plant design and management practices will minimize unwanted rainfall input to certain areas of the plant, whilst allowing collection of rainfall that can be used to offset freshwater use.

Category II will be the focus of this paper to reduce the major water losses in the following areas:

- Losses via cooling tower.
- Losses with the hydrate product in calcination.
- Losses with bauxite residue disposal.

4.1 Seawater Cooling Towers

Seawater cooling is commonly used in power plants and alumina refineries built on the coastline. The use of seawater cooling for the boiler plant and process cooling towers results in significant reduction of specific water consumption, of 1.75 t/t.

Seawater cooling systems in alumina refineries use one or more internal freshwater cooling circuits. The internal cooling water stream is then cooled in large plate heat exchangers with seawater. There are two advantages with such configuration. It reduces the risk of sea water contamination to the process, and at the same time reduces the risk of caustic contamination of the seawater, which could then be released to the environment.

Cooling of precipitation slurry in plate or shell and tube heat exchangers carries the risk of caustic contamination of the cooling water by holes in the heater tubes or plates. The cooling water must be continually monitored for conductivity as a measure of caustic contamination. Cooling of spent liquor in evaporation plants also carries the risk of caustic contamination of the cooling water, but to a lesser degree than precipitation because no abrasive slurry is involved. The internal cooling for these two duties is often combined due to the contamination risk.

The cleanest cooling water duty in the refinery is calcination cooling water for alumina product. The internal calcination cooling water circuit is usually separate to the precipitation and evaporation circuits because there is no risk of caustic contamination.

4.1.1 Air Cooled Cooling Towers

Where seawater is not available or not applicable because of location and/or environmental concerns, air cooled heat exchangers using fin-fans could be used in place of cooling towers.

Though air cooling is technically feasible to reject the heat from the cooling water to atmosphere, the cost could be prohibitive due to lower efficiency in heat exchange.

4.1.2 Minimizing Water Losses in Residues

The base case has adopted mud filtration for reduction of moisture losses with bauxite residues. The conventional mud washing is kinetically less efficient and therefore requires large vessels and large amount of water to complete the washing process.

Further reduction in freshwater usage would point to using the slurry filtration either directly after flash trains or after settler clarification. This will not only significantly reduce the refinery footprint and capital cost, but also may reduce the freshwater usage for mud washing.

One of the approaches is to possibly filter the digested BOF slurry. This was practiced at several older refinery sites in the past with older filtration technology than currently available and abandoned due to the associated labor-intensive operational difficulties. Hogan and Furlong [2] have discussed in detail about the potential use of direct filtration of BOF slurry. The major drawback of direct filtration of BOF slurry is the dilute feed and therefore large filter areas are required. This could be overcome by incorporating the mud settling process before filtration, that is, filtration of settler underflow (SUF) mud using press filters. Cake washings are potentially possible as filtration technology continuously improves.

4.1.3 Minimizing Water Losses in Hydrate Product and Calcination

The moisture in product hydrate has been considered as typical in the base case, by using the best practice in operation, and therefore is not further explored in this study.

One of the potential breakthroughs is two stage calcination (see Ilievski [3]) which can potentially recover significant amount of water vapor from the calcination process.

Without going into details, the key aspects of the two-stage calcination are:

- Stage 1 Calcination, also called decomposer, is conducted at higher pressure with superheated steam at ~480°C and >6 Bar to produce partially calcined alumina.
- The steam used in the Stage 1 Calcination is provided by recycled steam from both Stage 1 and Stage 2 Calcination.
- The water of crystallization released in the Stage 1 Calcination adds to the steam input. The total steam output is cleaned and returned to the plant at roughly the medium pressure of 6 to 8 Bar with a portion of the cleaned steam recycled to Stage 1 Calcination.
- The partially calcined hydrate is then fully calcined in Stage 2 Calcination at atmospheric pressure. The product is cooled in a conventional way.

As mentioned by Ilievski [3], the two-stage calcination has a potential to reduce the energy consumption by 1.1 GJ/t and recover water vapor of 0.4 t/t alumina produced. However, the technology is still in preliminary pilot plant stage and the commercial implementation still depends on future development. One of the key challenges is whether the two-stage calcination will meet the product quality requirements.

4.1.4 Recovery of Digestion Blow Off (BOF) Steam by MVR

As mentioned before, digestion BOF steam (representing a loss of 0.15 t/t) is currently vented to atmosphere. One way to recover this is by using mechanical vapor compression to electrically compress the atmospheric pressure steam to the required medium pressure plant steam, for example, 6 to 8 Bar. Alternatively, the low-pressure vapor could be condensed by an additional cooling process, but the cost will be likely much higher than the method of mechanical compression.

4.2 Category III – Minimizing Live Steam Consumptions

The major live steam consumptions are in digestion for slurry heating and in evaporation for liquor evaporation.

4.2.1 Slurry Heating

Bauxite slurry is conventionally heated using live steam. However, heating without steam has been applied in the past by use of a thermal storage fluid. With green energy becoming more and more economical, slurry heating using thermal storage medium such as molten salt or oil can be an option to reduce the live steam consumption in slurry heating, and the associated water losses with generating this steam. The implementation of such technology will go in parallel with decarbonization development in the refinery. We believe future implementation of molten salt heating is possible.

4.2.2 Evaporation by Use of MVR

In conventional evaporation plants, the driving force of evaporation is provided by live steam heaters, with heat then being recovered from multiple flash stages to heat the incoming spent liquor in shell and tube heat exchangers. After the last recuperative flash stage, barometric condensers are used to maintain the necessary pressure profile down the stages. The disadvantage of this approach is that heat is rejected to cooling water in the barometric condenser stages. Because of this, the energy content of the vapor stream is only partially recovered to the spent liquor. Any way of reducing live steam consumption will in turn reduce water consumption required for boiler feed water makeup. In this case freshwater makeup to the associated evaporation cooling tower will also be reduced.

MVR can work with the main types of evaporation plant used in alumina refining including multiple effect flash evaporators and falling film evaporators. The technology works by using electrical energy to compress low pressure process vapor to a higher pressure. Electrical energy to drive the compressors replaces live steam as the energy source. The technology has been used in other industries, so it is believed MVR can be properly implemented in alumina refinery (see references [4] and [5]).

The live steam usage for the base case refinery is about 0.48 t/t alumina. If this amount of steam can be saved, it will represent an equivalent reduction of boiler feed water of 0.34 t/t.

5. Discussions and Future Direction

In locations where seawater cooling is allowed, Figure 10. shows the reductions in freshwater usage from 2.40 t/t to 1.91 t/t after the technologies of MVR in evaporation (-0.34 reduction) and BOF (-0.15 reduction). The total evaporation loss in the Base Case is about 1.75 t/t. Implementation of seawater cooling will potentially reduce freshwater usage by 1.41 t/t on top of MVR's implemented (-1.75 + 0.34 = 1.41 t/t).

Preliminary modeling has indicated that direct filtration of settler underflow does not reduce much freshwater usage if the whole plant water and caustic balance is to be maintained in a scenario where reduced water losses leads to increased internal recycling of water. Further detailed analysis is required for this matter.

Two-stage calcination is capable to reduce 0.4 t/t of water losses via calcination according to Ilievski [3].

The net result would then be a net freshwater consumption of 0.10 t/t water as shown in Figure 10.

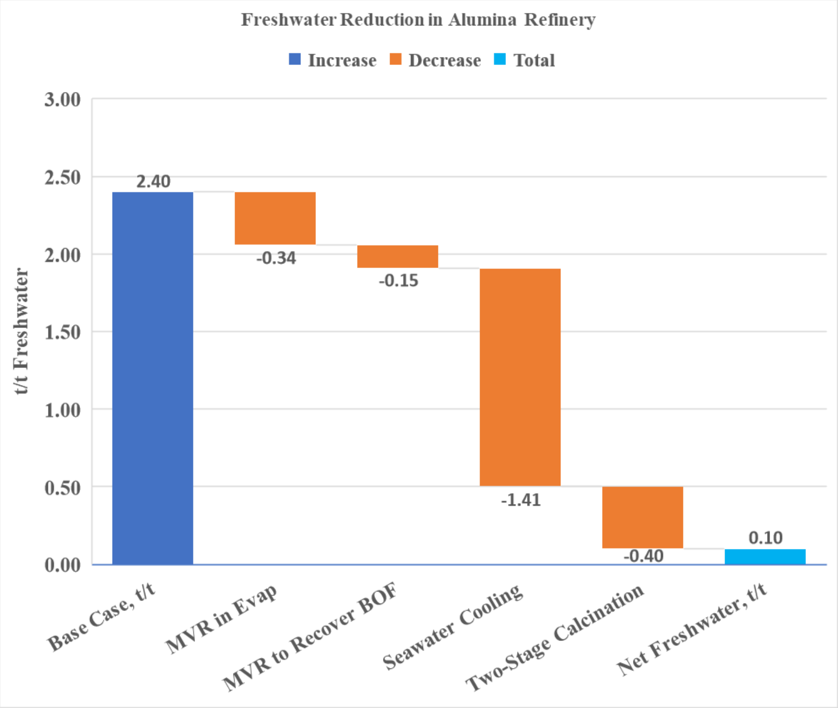


Figure 10. Freshwater reductions – Seawater cooling available.

In locations where seawater cooling is not available, the first choice for reduction is MVR in evaporation and BOF recovery, then two-stage calcination. The final consumption stands at 1.51 t/t, see Figure 11.

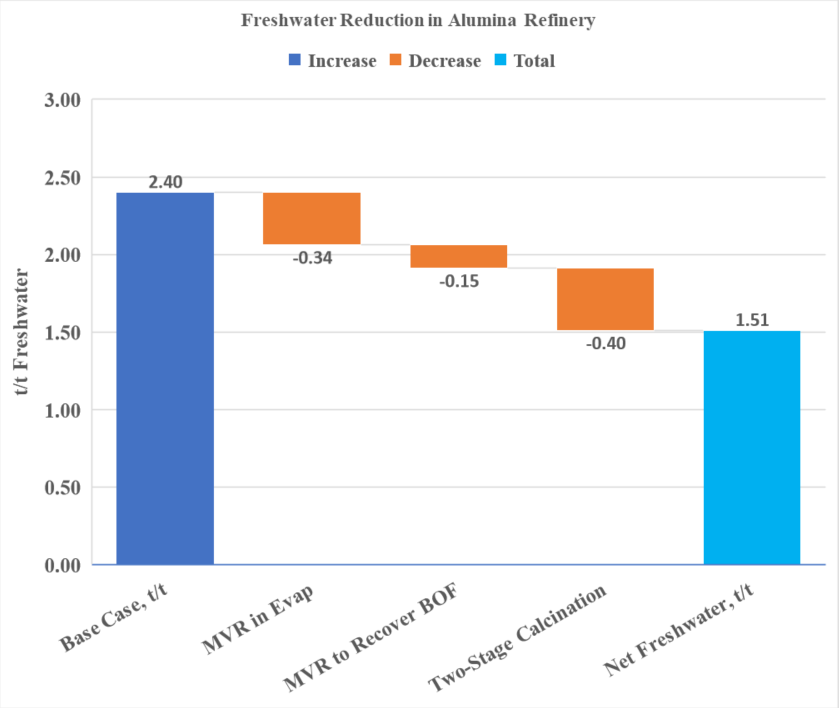


Figure 11. Freshwater reductions – Seawater cooling not available.

In summary, it is relatively easy for the refineries with seawater cooling available to envisage zero freshwater consumption, together with the implementation of MVR in both evaporation and blow off steam recovery.

We recognize that significant efforts are still required in terms of development in both equipment technologies and design innovation. For implementation of each new technology, diligent evaluation of pros and cons as well as inherited risk must be fully conducted.

For locations where seawater cooling is not available, there is a gap to net zero freshwater consumption even with the implementation of MVR in evaporation and BOF recovery, and two-stage calcination. However, there will likely be further opportunities to deploy technology solutions for a “net-zero” water refinery than discussed herein.

Several of the proposed water reduction technologies are synergistic with refinery decarbonization pathways. Worley is committed to the development of “green” alumina refineries that help our customers navigate towards a net zero world.

As a socially responsible engineering service provider, Worley delivers more than consulting, engineering, procurement, and construction services: we are delivering a more sustainable world!

6. References

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