AA26 - Importance of Water Balance in an Alumina Refinery

Brian Kissane
Process Engineer
Aughinish Alumina Ltd., Askeaton, County Limerick, Ireland
Corresponding author: brian.kissane@augh.com

Abstract

The Rusal Aughinish Alumina (AAL) refinery is located on Aughinish Island on the shore of the Shannon Estuary 33 kilometres west of Limerick city in the South West of Ireland. The plant commenced operation in 1983 and has a current production capability of 1.99M tons per annum. It sources bauxite predominantly from Guinea and Brazil and uses the Bayer process to produce alumina. For a chosen plant design and technology, production, costs and product quality can be optimised within the specific boundaries of the refinery. One of the key ingredients to deliver these optimum conditions is the management of the water balance in the refinery. Aughinish alumina refinery does not have a stand-alone evaporator as most alumina refineries would have so it fully relies on a tight water balance management. The contributors (inputs and outputs) to the water balance come from all process areas in the refinery, with some factors having a larger influence than others. There are a number of reasons why the water balance needs to be controlled and these reasons can be categorised into areas: deliver sufficient plant evaporation capability to achieve adequate tank movements in the precipitation circuit, optimisation of controllable caustic consumption and impurities management. The water balance is reviewed daily in the refinery and adjustments made to ensure the inputs are controlled relative to the outputs. The paper details how the water balance in an alumina refinery is managed.

Keywords: Alumina refinery, water balance, evaporation capability.

1. Introduction

Aughinish was commissioned in 1983 with a design capacity of 800 000 tonnes per annum. The refinery design was based on high quality dry CBG (62 %) and dry MRN (38 %) bauxites. The refinery was designed using the best available technology at the time: a Kaiser digestion design, an Alcan precipitation design and Alcoa calciners were installed. Aughinish was designed without a stand-alone evaporator. Evaporation capability is directly linked to processes such as digestion extraction, liquor cooling and heating, impurities concentration/removal. A single chain was built originally and today the refinery is still operating on that single chain, but the production capability has been increased to approximately 1.99 M tons per annum.
This paper looks at the main contributors to the water balance in the refinery. It details the impact of the main inputs and outputs as well as equipment changes that can have an influence. The role of the Process Control Group who review and make changes to the water balance on an ongoing basis is also discussed.

The water balance in the refinery can also be referred to as the plant volume and the terms will be used interchangeably throughout this document.

2. Water Balance is Part of the Process Flow Diagram of the Refinery

For the purpose of the water balance, an alumina plant may be considered as a large volume of liquor and solids that is contained in and circulated through a series of tanks and pipework. At various different points in the process, additions (inputs) and subtractions (outputs) are made [1]. Figure 1 below displays a boundary around the main areas within the refinery. The streams entering and exiting this boundary are the main inputs and outputs to the plant [2]. All these items contribute to the water balance within the plant. The Process Control Group must ensure that the inputs are controlled relative to the outputs. As the additions and subtractions are not always equal, there are some fluctuations in the water balance. Small fluctuations in the water balance can be tolerated as there is a small surge volume within the equipment but these changes need to be tightly controlled.

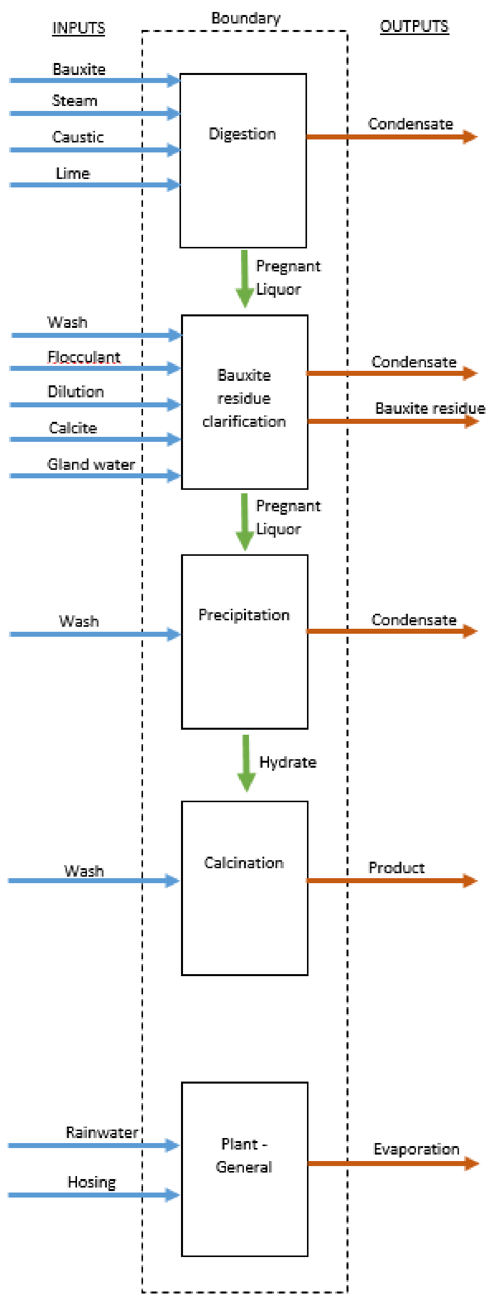

Figure 1. Water balance process flow diagram.

2.1 Inputs

Digestion

Bauxite: Bauxite is charged to digestion in line with plant flow and the required digester ratio. The moisture content of the bauxite and the available alumina in the bauxite also impact the plant volume. Bauxite with a higher moisture content and less available alumina will increase the water balance in the plant. The blend of bauxite being processed has an impact on the water balance including proportion of sweetening bauxite which reduces the net evaporation in the digestion and increases the water input in the plant. See section 9 for further details.

Steam: high pressure steam produced in the boiler house is injected into the digesters to achieve the necessary temperature and pressure conditions to extract the alumina from the bauxite. The volume of steam required is impacted by a number of factors including the number of flash tanks online and the number of heat exchangers online and their performance.

Caustic: caustic addition to the plant is required to keep the recirculating liquor at a desired concentration and to maintain production.

Lime: lime addition to the digester has a number of functions. It is important for extraction, impurities and iron control and also for bauxite residue settling performance.

Bauxite residue Clarification

Wash: sand washing and bauxite residue washing using condensate are the main areas where additions to the water balance are made in the bauxite residue circuit for the purposes of recovering caustic back into the process. Caustic is a high cost plant consumable so minimisation of consumption via waste streams is desirable. Higher wash volumes increase the water input in the refinery.

Flocculant: flocculants are added to the bauxite residue circuit to help with settling and to achieve an acceptable overflow clarity. The flocculant dosage is directly linked to the bauxite residue loading through the area; higher bauxite residue load results in higher flocculant dosage.

Dilution: dilution is added with the flocculant to reduce the viscosity of the floc and to promote improved mixing with the bauxite residue liquor.

Calcite: calcite is added as a stabilising agent to the decanters and first washer. It is added at a fixed flowrate.

Gland water: gland water is used throughput the plant for pumps without mechanical seals. Gland water usage must be maintained to a minimum as it can be a significant addition to the water balance.

Precipitation

Wash: condensate wash is used when required to remove solid phase oxalate from seed. It also has the secondary benefit of reducing caustic concentration in precipitation which increases super saturation and consequently productivity.

Calcination

Wash: condensate wash is added to the filters in calcination to reduce the leachable soda in the alumina. The ratio of condensate per ton of hydrate is adjusted to optimise soda in product and manage overall water balance when necessary. See further details in section 7.

Plant – General

Rainfall: the total bunded surface area of the plant is approx. 133 000 m^2 so therefore rainfall is a significant contributor to the water balance. In very wet conditions, rainfall can contribute up to 5 000 m^3/d of an addition to the water balance if not managed differently. Rain water can be diverted from process bund areas to emergency ponds in periods of heavy rain to avoid too much water getting back to the process.

2.2 Outputs

Condensate

Condensate is an output from a number of different areas in the refinery. The condensate production in the digestion unit accounts for approx. 50 % of the total water balance output in the plant. This condensate production depends on the spent liquor flow to digester and the performance of the heaters in the digestion unit. Condensate is also produced in the impurities removal area and in the precipitation area. In the impurities removal area, a stream of spent liquor is concentrated by evaporation and is dependent on heat exchanger performance. The condensate from the precipitation area is produced by vacuum flash cooling of incoming pregnant liquor and is also dependent on heat exchanger performance.

Bauxite residue

Bauxite residue is taken from the bauxite residue circuit, filtered, washed and sent to the bauxite residue disposal area and is a reduction in the water balance in the plant.

Calcination

Hydrate: the removal of hydrate from the plant is one of the major water balance reductions. The removal of hydrate is based on the production.

Plant – General

Evaporation takes place from the liquor surface in various tanks throughout the plant. This is a relatively constant value and low in Ireland.

3. Maintenance Plan for the Refinery and Requirement to Water Balance Forecast

The maintenance plan for the refinery has a significant impact on the successful operation of the refinery as it impacts on production, product quality, energy efficiency and the water balance. An Annual Refinery Maintenance Plan is generated in conjunction with the Annual Business Plan prior to the start of each year. The maintenance plan highlights the scheduled maintenance for the large items of equipment within the refinery. A 52 week Equipment Maintenance Plan is generated based on the information from the maintenance plan. This schedule details the timeframe for the maintenance on each equipment item and identifies any potential clashes that may occur i.e. certain items cannot be on turnaround at the same time as they will have too much of an impact either on safety/environment or production or energy efficiency or the water balance e.g. a flash tank outage in digestion and a gas turbine outage can't occur together due to energy efficiency issues. A 6 Week Plan is then generated to micromanage the equipment maintenance as it occurs. This plan is reviewed numerous times weekly by various different disciplines and is coordinated by the Plant Equipment Coordinator. The plan details the impact of the maintenance on each of the key refinery metrics including plant volume. Precipitation tank outages, decanter switches and flash tank outages in digestion are the key items from a water balance perspective as they all have a significant impact. Decanter switches happen quickly and are most disruptive. These switches require a large volume of liquor in precipitation before the switch and a large volume of space (7 500 m^3) after the switch to take the pump off from the decanter that has come offline. Flash tank outages in digestion have a smaller but more prolonged impact on the water balance. Some flash tank outages can result in 20 m^3/h less evaporation capability for up to 2 weeks depending on the length of the turnaround. This reduction in evaporation has to be balanced with plant inputs in order to keep the water balance in control for the duration of the outage. Other process vessel turnarounds happen much more slowly and are prepared for a number of weeks before the change – it is easier to manage these from a water balance perspective.

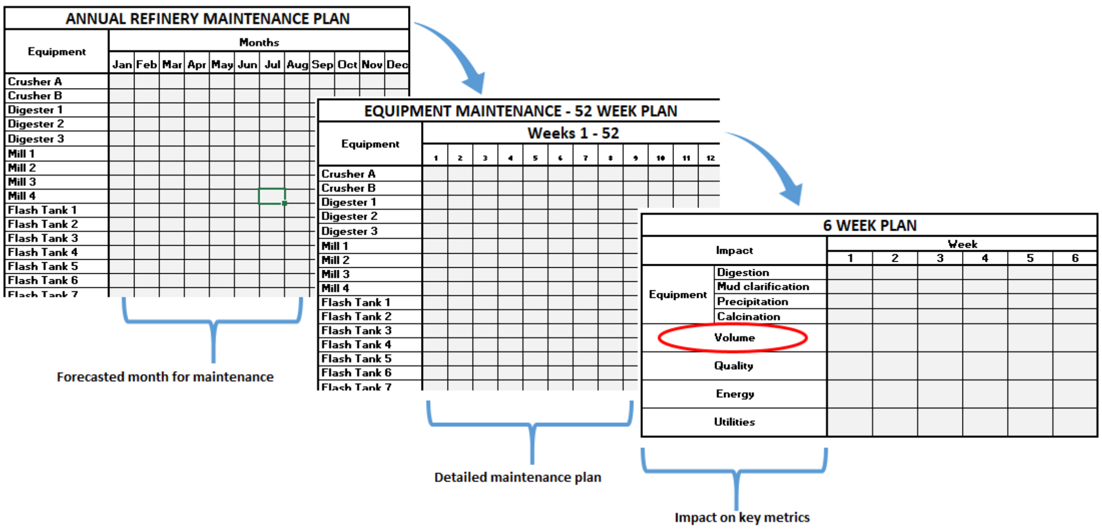

Figure 2. Plan examples.

4. Daily Water Balance Management

In order to manage the water balance on a daily basis, a Process Book display is used – see Figure 3 for an example. The Process Book display monitors the key inputs and outputs on a real time basis and is reviewed by the Process Control Group on a daily basis. Based on how parameters have changed over the previous time period, decisions are made on which parameters are to be adjusted to optimise the water balance for upcoming events.

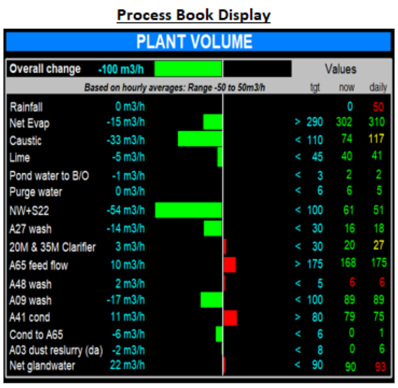

Figure 3. Process book display example.

5. Plant Caustic and Volume Control

Spent liquor is pumped from the precipitation area to the digestion area and is stored in "test tanks". These tanks provide the liquor for the digesters. The caustic concentration within the test tanks is controlled by the Process Control Group and is adjusted to maximise plant productivity under the prevailing conditions. The concentration in the test tanks is adjusted by adding caustic from the caustic surge tank. There is also an automatic test tank control scheme that controls the caustic inventory in the plant based on the plant volume. This control scheme is necessary, as the addition of fresh caustic to the refinery when the water balance is increasing will result in an excessive inventory of caustic when the water balance returns to normal.

For example, if the plant volume is on target at 0 m^3 and the test tank caustic is set at 268 gpl, then the inventory of caustic in the plant is:

$$Caustic\ Inventory = 212\,000\,000\ L\ liquor * 268\ gpl\ caustic\ as\ Na_2CO_3 = 56\,816\ t$$

where 212 000 m^3 is the base volume of the refinery.
If the water balance in the plant increases by 10 000 m^3 and the same test tank caustic is maintained then the caustic inventory increases to:

$$Caustic\ Inventory = 222\,000\,000\ L\ liquor * 268\ gpl\ caustic\ as\ Na_2CO_3 = 59\,496\ t$$

If the water balance in the plant contracts back to the base volume of 0 m^3, then the test tank caustic will have increased due to the higher caustic inventory in the plant:

$$Test\ tank\ caustic = \frac{59\,496\ t}{212\,000\ m^3} = 280\ gpl$$

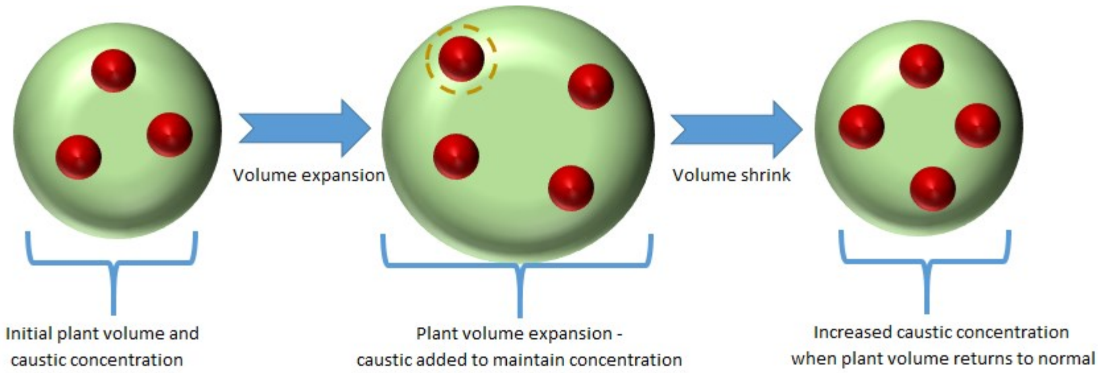

Figure 4. Plant volume and caustic representation.

The higher test tank caustic can impact severely in different areas of the refinery including in bauxite residue separation where it can impact on settling velocities and in precipitation where it has the potential to cause a solid phase oxalate event. Therefore, the test tank caustic controller automatically cuts the test tank caustic target by 1 gpl once the gap between the target volume and actual volume is greater than 3 000 m^3. For every subsequent deviation of 1 000 m^3 over the target volume, the test tank caustic is automatically cut by a further 1 gpl.

Table 1. Example of plant volume and associated test tank caustic.

Target volume (m^3)	Actual volume (m^3)	Difference (m^3)	Test tank caustic target (g/l)
0	1000	1000	Target
0	2000	2000	Target
0	3000	3000	Target – 1 gpl
0	4000	4000	Target – 2 gpl
0	6000	6000	Target – 4 gpl

To prevent the automatic change of test tank caustic concentration by the caustic controller, the Process Control Group monitors the actual volume and target volume. The target volume is adjusted by the Process Control Group to keep within the 3 000 m^3 tolerance which in turn mitigates any unwanted changes to test tank caustic. This results in expansions or contractions to the water balance being managed in a more controlled fashion.

6. Evaporation Capability and Energy Efficiency Optimisation

6.1 Evaporation Capability

Net evaporation is the term used to monitor the impact of the digestion area on the water balance. It includes a measure of the condensate produced from the heat exchangers in digestion as well as other methods of exporting steam and thus removing water from the flash chain. During normal operation, alumina is extracted from the bauxite slurry by heating with steam injection to approx. 250 °C in the digesters. Once the alumina has been extracted, the slurry is cooled by dropping the pressure in a series of ten flash tanks resulting in the generation of steam. There are two shell and tube heat exchangers associated with each online flash tank and the steam from the flash tanks is used to heat spent liquor that passes through the tube side of the heat exchanger. The efficiency of the heat exchangers and subsequent condensate production has a major impact on the water balance in the plant i.e. more efficient heaters will result in more steam being flashed off in the flash tanks and consequently more heat transfer to the spent liquor. The heat transfer coefficient (HTC) of the heat exchangers is continually monitored and is used to plan and forecast upcoming changes in the water balance of the plant. The heat exchanger cleaning schedule, planned flash tank outages and planned heat exchanger maintenance also feed into the forecast to give a visual representation of when the average HTC of the heat exchangers will be below a threshold that will have a significant impact on the water balance. An example of the HTC forecast for the high temperature heat exchangers is shown in Figure 5 below.

It can be seen from the chart that certain flash tank outages have a significant impact on the overall HTC of the heat exchangers. Changes to the water balance will be required in advance to negate the impact of these outages.

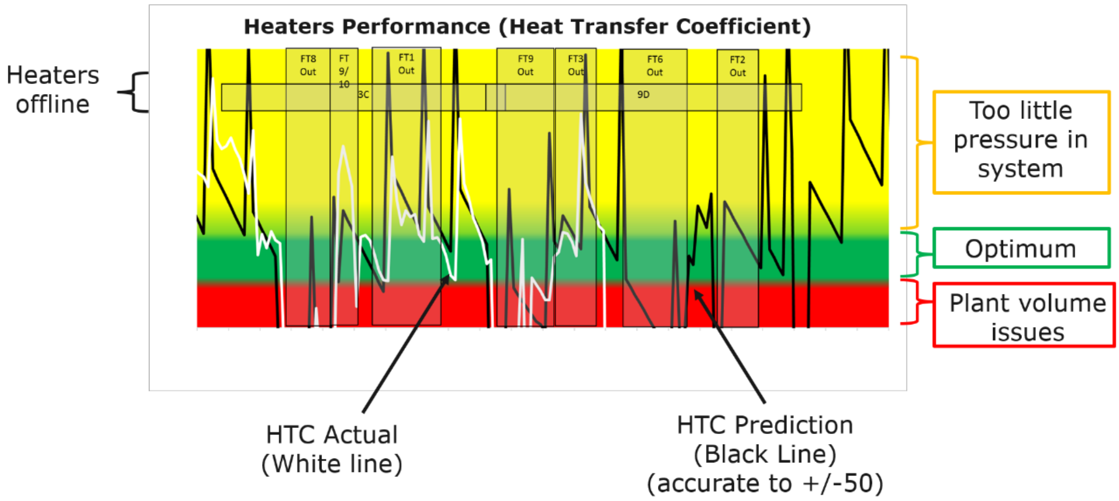

Figure 5. Example of heat exchanger HTC forecast.

6.2 Energy Efficiency Optimisation

At Aughinish, energy usage accounts for significant portion of the total operating cost. Therefore, energy efficiency is a high priority for the refinery. The refinery operates to an Energy Management System (EnMS) that is certified to an internationally recognised standard ISO50001. An EnMS is a systematic process for continually improving energy performance.

From a water balance perspective, energy efficiency relating to steam usage in digestion is a key factor as it uses approx. 96 % of the steam that is generated in the boiler house. A number of continuous improvement projects from an energy perspective are ongoing or planned and these will have a positive impact on reducing the water balance in the plant. These include a heat exchanger retube programme and an extensive insulation programme. The heater retube project is required to repair leaking tubes in the heat exchangers in digestion. The tubes are subjected to an erosion/corrosion phenomenon which gradually reduces their wall thickness until such time as they perforate and leak. The basis of the project is that heater retubes will be completed based on energy efficiency rather than mechanical performance. By completing a number of retubes each year, the retube interval reduces and the average HTC (i.e. energy efficiency) stays higher.

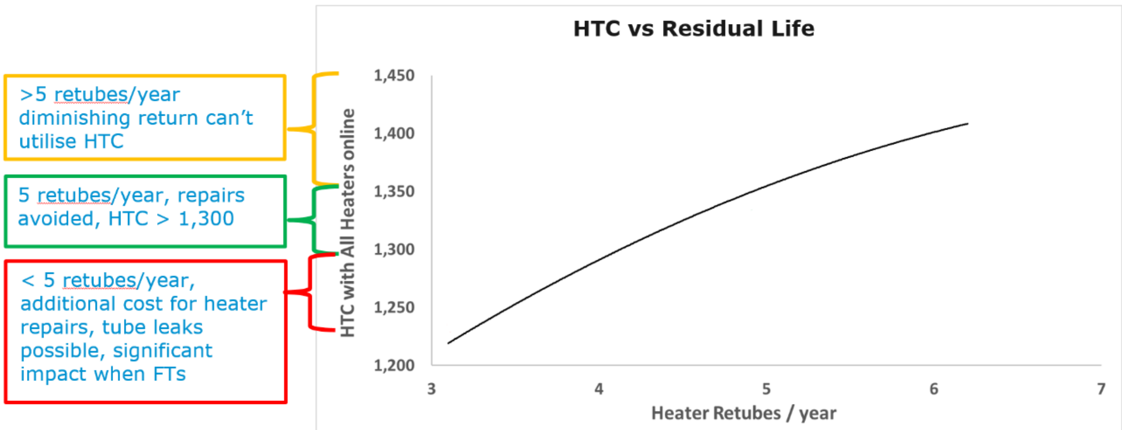

Figure 6. Impact of retube project on heat exchanger HTC.

With a higher HTC, the impact on the water balance of taking flash tanks offline for scheduled maintenance will be much less.

The insulation programme will focus on reducing heat losses from pipework in the digestion area in order to make more efficient use of the regenerative steam from the flash tanks.

Both projects will enhance the energy efficiency in the digestion area and increase net evaporation and hence provide more flexibility for the water balance.

7. Controllable Caustic Consumption – Direct Impact from Water Balance

Controllable caustic consumption relates to caustic that is consumed through various streams exiting the process. The quantity of caustic that is consumed is influenced by the water balance in the refinery i.e. caustic consumption can be reduced if condensate washes are increased or if streams are recovered back into the process but this is not always prudent from a water balance perspective.

7.1 Product Quality

Total soda in the alumina product is made up of both residual soda and leachable soda. Residual soda is bound within the hydrate particles and leachable soda is on the particle surface. Therefore, the leachable soda is the part that can be impacted by the water balance. Washing the hydrate with condensate reduces the leachable soda. This washing is completed on pan filters in the calcination area that are feeding the calciners. The wash distribution across the filters is critical to ensure maximum removal of soda. The condensate wash is an addition to the water balance and is optimised for soda and water balance control.

7.2 Bauxite Residue Washing

The sand and bauxite residue that are separated from the liquor stream is washed with condensate to recover as much caustic as possible before disposing in the bauxite residue disposal area. The condensate wash is an addition to the water balance. The bauxite residue is washed in the bauxite residue clarification area using a counter current washing system and is then further washed on drum filters in the filtration area prior to disposal. The sand fraction is washed in sand washers and screw classifiers prior to being disposed. The quantity of sand and bauxite residue to be washed varies depending on the available alumina in the incoming bauxite. Bauxite supplies are continuing to have a downward trend in available alumina in recent years. Lower available alumina results in an increased amount of sand and bauxite residue (Figure 7). The quantity of sand is also dependent on the number of mills online in the comminution area. Four mills online is the optimum number with any number less than this resulting in a larger grind size and more sand generation in the sand separation area.

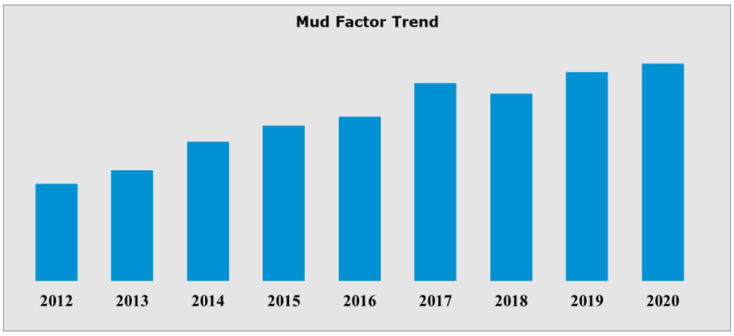

Figure 7. Bauxite residue factor trend in recent years.

The condensate wash and bauxite residue wash ratios are always the first items that are adjusted when the water balance isn't favourable.

8. Precipitation Tank Cleaning Schedule

Due to the scaling nature of the pregnant liquor and settling out of solids, the tanks in the precipitation area need to be taken offline at regular intervals for caustic cleaning. The cleaning schedule in figure 8 below is an example of how the caustic cleaning for the tanks is tracked. It details the frequency of caustic cleaning required and the number of days left until a caustic clean is next due. The cleaning frequency is based on the scaling rate of the precipitator with seeding precipitators having a higher scaling rate than those further down the chain.

Precipitation

	C/C Freq	Days Left	Res Life %
A1	240	213	89 %
A2	240	97	41 %
A3	240	12	5 %
A4	150	88	59 %
A5	150	36	24 %
A6	150	71	48 %
A7	150	110	74 %
A8	150	144	96 %
A9	150	0	0 %
A10	150	59	39 %
A11	550	461	84 %
A12	550	174	32 %
A13	550	407	74 %
A14	550	336	61 %
A15	550	0	0 %

Figure 8. Precipitation tank cleaning schedule example.

The overall water balance can be split into three separate calculations when it is being assessed from a tank movement perspective: volume, liquor, space. Each of these categories need to be considered together to adhere to the precipitation caustic cleaning schedule.

The volume calculation takes the base volume of the plant at 212 000 m^3 and equates it to 0 m^3. The volume calculation assumes that a certain number of tanks in different areas of the refinery are offline and empty. Any changes from these assumptions will positively or negatively impact the volume figure. Changes in the volume figure on its own indicates if the water balance in the refinery is contracting or expanding.

The liquor number corresponds with the volume of liquor that is available in the precipitation area of the refinery. This includes offline precipitators and classifiers. This is the spent liquor that can be used to fill a tank to bring it online if required. A minimum volume of 5 000 m^3 of liquor always needs to be kept in the precipitation area to ensure capacity is available for pumping to the digestion area to maintain plant operation.

The space calculation is the most critical to facilitate the precipitation tank cleaning schedule. Having available space in the precipitation circuit allows liquor to be moved so that tanks can be cleaned and maintained i.e. in order to clean a tank the liquor must be pumped out of it to another tank.

The Process Control Group must take into account the upcoming tank movements a number of weeks in advance to ensure the required space or liquor is available in good time and thus ensuring the water balance is kept in control.

9. Bauxite Quality and its Impact on Water Balance

As mentioned in section 7.2 above, the available alumina of the bauxite is on a downward trend in recent years. Some bauxite ships also have a higher moisture content. Again, this impacts on the water balance with more water input to the process for the same hydrate output. These changes in bauxite need to be counteracted by adjusting other inputs to the process to keep the water balance in control. As detailed in section 6 above, continuous improvement projects have been implemented to increase net evaporation as this is the preferable route for counteracting additions to the water balance due to bauxite. Otherwise condensate additions for washes in other parts of the refinery are impacted e.g. bauxite residue washes are reduced which then impacts on controllable caustic consumption as per section 7.

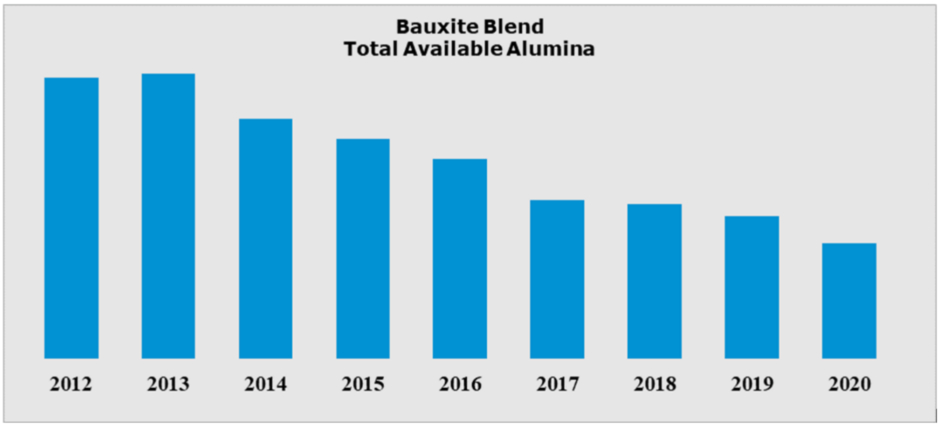

Figure 9. Available Alumina trend for recent years.

10. Water Balance Challenges and Opportunities at Aughinish Refinery

10.1 Challenges

Bauxite quality continues to be a challenge with the percentage of available alumina in the bauxite on a downward trend. The impacts of this on the water balance are numerous:

- Less available alumina in the bauxite corresponds to higher bauxite tonnage requirement and additional water input and additional impurities which require more lime and more seed washing in precipitation.
- More bauxite residue is produced when there is less alumina in the bauxite. This requires more washing for the same amount of hydrate production. The additional washing requires an equivalent reduction somewhere else in refinery.

10.2 Opportunities

Steam usage in digestion is the main area where there is an opportunity to reduce the water balance. As detailed in section 6.2, the insulation project and the heat exchanger retube projects are key to improving steam efficiency and consequently reducing the water balance.

Alternative sources of water are being explored for flocculant and other additive preparation and dilution. The installation of a Deep Cone Thickener in the mud circuit will help in this regard.

Indirect bauxite slurry heating is also an opportunity to eliminate the use of direct steam injection in the process.

11. Conclusions

The Aughinish refinery now operates at a much higher capacity than its original design but the primary equipment has predominantly remained the same. Combining this with the many constantly changing factors associated with the water balance makes it a challenging task for the Process Control Group to manage daily. It is critical that the water balance is kept in control not just from a safety perspective but also from a product quality and production perspective. New opportunities are constantly being explored that can reduce the water balance in the refinery. Any new options that change the water balance need to be considered carefully and the impacts on the different aspects of the refinery as discussed in this paper need to be assessed.

12. References

1. Damien Clancy, Plant Volume Control, *AAL Internal report*, 1984.
2. Bryan Hiscox, Plant Volume Control, *AAL Internal report,* 1987.
3. Stephan Beaulieu, The Road to a New Bauxite – Mine and Refinery Optimisation, *37th International ICSOBA Conference,* September 2019.