

## **Design, startup and operation of the new digestion facility at the Ma'aden Alumina Refinery**

**Brady Haneman<sup>1</sup> and Brandon Lindsay Rae<sup>2</sup>**

1. Director Light Metals (B&A), Hatch Associates Ltd, Australia

2. Technical Manager, Ma'aden Alumina Refinery, Saudi Arabia

Corresponding author: bhaneman@hatch.com.au

### **Abstract**

The sustainable operation of a new high temperature alumina refinery in an emerging mineral processing region with a hot climate provides many unique challenges. Avoidance of operational complexities and reducing the labour intensity more typically associated with these high temperature process plants required a bespoke approach to the refinery flowsheet development and design. The Az Zabirah deposit is a high boehmitic grade bauxite. In assessing the optimal flowsheet, options ranging from a full tubular digest to conventional dual (or split) stream flowsheets and hybrid versions incorporating direct injection heaters were reviewed. Whilst energy efficiency, capital and operational costs were key flowsheet assessment parameters, considerations for maintainability were paramount. As such, the digestion facility for the Ma'aden Alumina Refinery utilizes a new hybrid tube digestion design developed specifically to process the Az-Zabirah bauxite at Ras Al Khair. The refinery incorporates two digestion units that encompass both aspects of tubular digestion technology and more conventional digesters to achieve its nameplate 1.8 Mtpa smelter grade alumina. This paper reviews the unique design and operating solutions developed as well as the operating experiences and plant performance since startup of the Ma'aden refinery in December 2014.

**Keywords:** Digestion; high temperature.

### **1. Introduction**

The Ma'aden alumina refinery located at Ras Al Khair in Saudi Arabia, is part of a fully integrated aluminium facility and once fully operational, will be the lowest cost aluminium complex in the world. The greenfield refinery has a nameplate capacity of 1.8 Mtpa smelter grade alumina and commenced operation in December 2014. The refinery processes a boehmitic and gibbsitic bauxite from the Az Zabirah deposit. As a result, a high temperature digestion process is employed to extract the alumina.

For a greenfield high temperature refinery operating in an emerging mineral processing region of Saudi Arabia, a strategic flowsheet objective to guarantee sustainable continuous operation was the avoidance of operational complexity and a minimization of labour intensity required to sustain equipment performance and reliability.

During the early phases of the project development, several high temperature digestion processing options were integrated into the refinery flowsheet and examined. Each flowsheet was assessed to provide the optimal balance between energy recovery, capital cost, operating cost, operability and of paramount importance, maintainability. Flowsheet alternatives incorporated a review of high temperature tubular digestion (with jacketed pipe heating), split stream digestion with the liquor heated separately to the bauxite slurry and various hybrid options utilizing both tubular digestion and traditional autoclaves with and without direct injection heaters.

The selected digestion option is a hybrid tube digestion flowsheet utilizing high pressure positive displacement slurry pumps, jacketed pipe slurry heating for the recuperative circuit and traditional autoclaves (or digesters). The gibbsitic alumina is extracted through the jacketed pipe heaters and the boehmitic alumina extraction occurs in the digesters. Pre-desilication is employed to extend recuperative heat transfer life.

## 2. Flowsheet overview

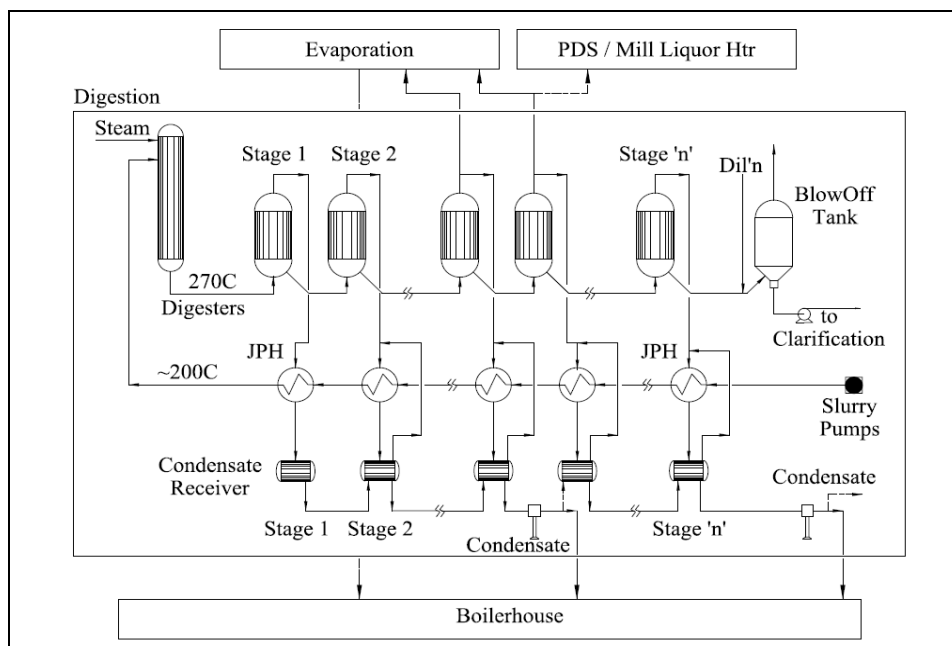
Figure 1 below represents a simplified flow schematic for the “hybrid” digestion facility. Multiple trains of single stream jacketed pipe heaters fed by positive displacement triplex piston diaphragm pumps are used to digest the gibbsitic alumina. The slurry is further preheated up to a controlled recuperative temperature limit of  $\sim 200$  °C. This limit is selected so as to avoid titanate scale formation through the heater tubes.

In limiting the recuperative temperature to this target, the aim is to avoid the requirement for on-going and labour intensive mechanical cleaning of the elevated temperature heater tubes with high pressure water jet blasting (or other means). Pre-desilication is incorporated into the slurry feed circuit using direct contact heaters. The targeted cleaning requirements for the digestion heater tubes is an estimated 9-10 week rotational cycle for acid cleaning to remove sodalite scale only.

After discharging from the jacketed pipe heaters, the slurry is then heated to 270 °C in digesters. The digesters are sized to provide sufficient residence time for the boehmite extraction. Direct steam injection is used to attain the requisite temperature for the reaction. The slurry is then flash cooled through the flash vessel train to atmospheric boiling point prior to being pumped to the clarification circuit.

As a result of the recuperative limit of  $\sim 200$  °C there is more energy available to be liberated from the vessel train than can be practically absorbed in the slurry heating circuit. Export steam from the flash tanks is therefore used as the low pressure live steam supply for the evaporation circuit live steam heaters supplying all low pressure steam demand. Additional low pressure and temperature steam from the flash tanks is used as export steam to both the pre-desilication direct contact heaters and the mill liquor heater.

To further reduce the energy usage for the refinery, additional energy recovery optimization features were incorporated into the process design. These include export of both, digestion condensate and evaporation “live steam” heater condensate (from the flash tank export vapour), back to the boiler-plant. Mid pressure and temperature condensate from the digestion unit is exported via plate heaters in the boiler-plant to exchange heat with the boiler feedwater. The subcooled mid pressure digestion condensate is then mixed with low temperature digestion process condensate as the initial pre-heating stage of the boiler feedwater.



**Figure 1. Hybrid digestion facility schematic.**

### 3. Major equipment design, process controls and safeguards

To attain the target digestion unit availability and enhance operational security and stability for the refinery flow, consideration for the provision of appropriate equipment sparing has been applied to all critical components of the digestion unit.

The salient areas incorporating equipment and piping redundancy includes:

- The high pressure positive displacement slurry feed pumps
- The jacketed pipe heater trains
- Digester vessels
- Back pressure control stations
- Flash tanks
- Condensate collection systems
- Pressure relief valve installations

#### 3.1 Jacketed pipe heaters

The jacketed pipe heater building (Figure 2) incorporates a spare heater train to ensure uninterrupted facility and refinery flows are ostensibly achieved during heater chemical cleaning rotations.

The building layout incorporates sufficient space for future extraction should heater replacement be required. The heaters have been designed such that the slurry flow is uninterrupted in an individual heater tube run from the entrance to the first heater to the exit from the last heater. The design employed for Ma'aden eliminates the tubesheet more typically found in a shell and tube heater and previous jacketed piped heater designs. With this design evolution, slurry cross flow between tubes and erosion of the tubesheet face is eliminated.

The individual heaters are connected via removable tube bends to allow mechanical cleaning of the tubes with high pressure water jet blasting or other means. Standard piping gaskets are used replacing special and expensive ring joint gaskets in previous designs. Shell side cleanout nozzles are also provided on the vapour heads for visual inspection of the shell and/or water jet cleaning. The heaters are designed with a floating tube bundle to cater for transients in tube and shell temperature differentials.



**Figure 2. Digestion jacketed pipe heaters.**

### 3.2 Digesters

The digesters provide the required residence time of ~ 20 minutes for completion of the Boehmite extraction. The Ma'aden digesters operate at elevated pressures of ~ 50atm and have an approximate 4" shell thickness. Historically, the digester vessels have been provided with internal baffles and agitators to achieve a requisite number of Continuous Stirred Tank Reactors (CSTR) in series. At elevated pressures and temperatures, maintenance of agitator seals imposes additional downtime. Descaling the internal walls and baffles together with agitator blade replacement incurs additional refurbishment costs for the equipment.

For Ma'aden, the digesters have been designed to achieve the required solids residence time without internal agitators and associated internal baffles. Computational Fluid Dynamic modelling (CFD) was undertaken to review a number of fluid entry and aspect ratio geometries such that an optimal configuration could be selected for further analysis. Both top inlet slurry entry with and without bifurcations as well as tangential feed arrangements were analysed. Physical modeling of the selected design was then executed by CSIRO in Australia to determine expected particle residence times. Refinement of the selected configuration was undertaken to ensure completion of the boehmitic alumina extraction. The fluidynamic impact of the direct steam sparge mass flow and injection point was also taken into consideration.

### **3.3 Flash tanks**

The flash tank train has been designed to retain the target number of operational flash stages during bypass operations of individual vessels. Each flash tank is equipped with pressure relief stations utilizing pilot operated pressure relief valves. The vessels have been designed with a bottom entry inlet configuration [1] such that the expanding three phase (solids, liquor and vapour) fluid flow is directed into a deflection (or witches) hat. Specially designed castings are used to maximize the erosion resistance of the internal components. The removal and dis-assembly of the internal components has endeavored to minimize scaffolding and hot work requirements inside the confined space. Vessel vapour nozzles are sized to fully extract main rotatable wear items.

Flash tank stages designed as export stages to the evaporators are fitted with external cyclonic separators to minimize vapour contamination to the shell and tube live steam heaters.

The vessel interconnecting piping layout incorporates level control elements and strategically located chokes to control the onset of flashing fluid flow in the piping system. These control elements and chokes also endeavor to reduce the likelihood of vapour bypassing (or short-circuiting) through the piping system. This assists in maintaining the target energy recovery of the recuperative circuit.

### **3.4 Process controls**

The provision of pump and heater train sparing together with a recuperative temperature which is both a target and a limit has needed additional control systems to be incorporated into the plant design. To mitigate the potential for incorrect lineups of pumps to respective online heater trains and digester vessels, critical valve stations have been fitted with multiple proximity sensors. These proximity sensors indicate valid field line-ups and act as both a start permissive for the pumps and control interlocks on incorrect valve operation. Valve stations fitted with these sensors include the positive displacement pump discharge manifold, the jacketed pipe heater train inlets and the digester feed manifold.

For manipulation and control of the recuperative temperature of  $\sim 200^{\circ}\text{C}$ , two control methods have been employed which act as both fine control and coarse control.

The fine control system employs level measurement on selected jacketed pipe heater shells and a controlled flooding to limit heat transfer. The coarse control employs motorized vapour valves at selected vapour reticulation manifolds. Once the limit of fine control has been exhausted, vapour isolation from the central control room may be enacted. The implementation of both the fine and coarse control systems assists the digestion unit performance in three salient ways. Firstly, in limiting the final recuperative slurry temperature we avoid the rock like titanate scale formation. Secondly, it maintains operation of the vessel train at the target flash tank pressure profile to optimize energy recovery. Finally, in maintaining the target flash tank train pressure profile, critical driving pressure differentials for slurry flow are retained.

### **3.5 Safeguards and overpressure protection**

Multiple overpressure protection systems are employed to ensure plant and personnel are kept in a safe working environment under transient operational conditions. Both passive and non-passive systems are utilized. Passive overpressure protection via installed pressure relief valves and/or

bursting discs, are incorporated for:

- The positive displacement slurry feed pumps
- Hydraulic expansion protection for the jacketed pipe heaters
- Digester and flash tanks
- High pressure steam delivery header
- Low pressure steam reticulation network
- Export steam users to evaporation, pre-desilication and mill liquor heaters
- Low pressure/temperature export condensate users
- High pressure/temperature export condensate users

Separately, non-passive systems incorporating protection by system design utilizing high integrity safety instrumented systems (SIS) and layers of protection analysis (LOPA) are also used. A SIS is used to isolate high pressure steam delivery to the digesters on loss of slurry feed pump flow. A LOPA study was used to define the mitigation methods necessary for reducing the likelihood and severity of pressure transients.

#### 4. Process and technical summary

Table 1 below summarizes the salient process parameters for the refinery and digestion facility operation. As the digestion facility is a considerable producer of excess steam, export streams of flash vapour and condensate from digestion form an integrated system for energy re-use between digestion, evaporation and the boiler-house. Refinery energy is then tightly linked with the performance of the export systems and the production of good condensate from the digestion unit.

**Table 1. Key refinery and digestion facility process targets.**

	Process Parameter	Unit	Target
1	Refinery annualized nameplate production	Mtpa	1.8
4	Digestion Heater train life before chemical cleaning	weeks	~ 9
5	Digester temperature	°C	270
6	Digestion Recuperative temperature	°C	~ 200
7	Digestion Condensate quality	μS/cm	≤ 100

#### 5. Startup, ramp up and operation

To date, the Hybrid tube digestion design utilizing jacketed pipe heaters has shown promise to be more resilient than the use of shell and tube heaters to high temperature Bayer scale. The jacketed pipe heaters have been operated at an average flow of 65 % nameplate and have yet to be mechanically descaled in one year of operation. Hitherto, the intent of the hybrid design to minimize costly and intensive maintenance has been largely achieved.

Due to the hybrid steam injection design, the required digestion reaction temperatures are achieved facilitating design alumina extraction targets.

## **6. Conclusions**

This paper outlines the strategic elements of the flowsheet development and digestion facility design incorporated into the new Ma'aden alumina refinery in Saudi Arabia. The flowsheet and detailed design sought a critical balance between refinery energy targets, operational flexibility and equipment maintenance activities, to provide a facility unburdened by many of the more typical labour intensive commitments found in other high temperature alumina refineries.

The digestion facility employs sufficient equipment sparing to provide near continuous facility operation and additional process control features to maintain optimal process performance.

## **7. Acknowledgement**

The input and support from Ma'aden and Alcoa in the flowsheet development and project execution is kindly acknowledged.

## **8. References**

1. Haneman, B., Wang, A. Optimising Digestion Flash Tank Design for the Alumina Industry, Alumina Quality Workshop, 2010.