Evolution of Tube Digestion Technology for Alumina Refining

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Abstract

Refineries processing Boehmitic or Diasporic bauxites require a high temperature digestion circuit to extract the alumina. These circuits typically operate at between 250°C to 280°C. Since the 1960's, many of the worlds high temperature digestion circuits operated as dual stream circuits with the caustic liquor heated progressively through shell and tube heaters using regenerative flash steam. The liquor and bauxite streams were then mixed at the autoclave or digester vessels. With increasing focus on maximizing extraction, energy efficiency, process simplicity and plant utilisation, tube digestion technology has been increasingly the technology selected for refineries around the world. The tube digestion flowsheet preferentially combines the bauxite and caustic liquor streams together in a single stream prior to regenerative heating. This paper provides a brief overview of the technology, outlining its evolution with a review of past, present and future installations. A comparative review of key refinery process parameters using the technology is also provided with the impact on capital and operating costs for the refinery as the process design deviates from the tube digestion flowsheet.

Keywords: Tube digestion; single stream.

Introduction

Alumina refineries use primarily the "Bayer" process to extract alumina from Gibbsitic, Boehmitic or Diasporic bauxites. The Bayer process utilises a recirculating stream of caustic soda to extract the valuable alumina from the bauxite in four main processing steps. These are: (i) Digestion, where the bauxite is dissolved in caustic soda generally at elevated temperature and pressure, (ii) Clarification, where the residue solids are separated from the now 'pregnant' caustic liquor, (iii) Precipitation, where the alumina is crystallized out of the caustic solution to alumina tri-hydrate ($Al_2O_3.3H_2O$) by seeding and cooling the solution, and (iv) Calcination, where the alumina is calcined from the trihydrate to alumina (Al_2O_3).

Refineries processing Boehmitic or Diasporic bauxites require a high temperature digestion circuit to extract the alumina. These circuits typically operate at between 250°C to 270°C. Since the 1960's, many of the worlds high temperature digestion circuits operated as dual stream circuits (refer Figure 1) with the caustic liquor heated progressively through shell and tube heaters using regenerative flash steam and mixed with the bauxite stream at the autoclave or digester vessels. In High Temperature facilities, duplex alloy steels and nickels are often employed in the heater tubes to offer erosion/corrosion resistance to caustic at elevated liquor temperatures above 170°C. Final digestion temperature conditions are typically attained with the use of direct steam sparging into the digester vessels.

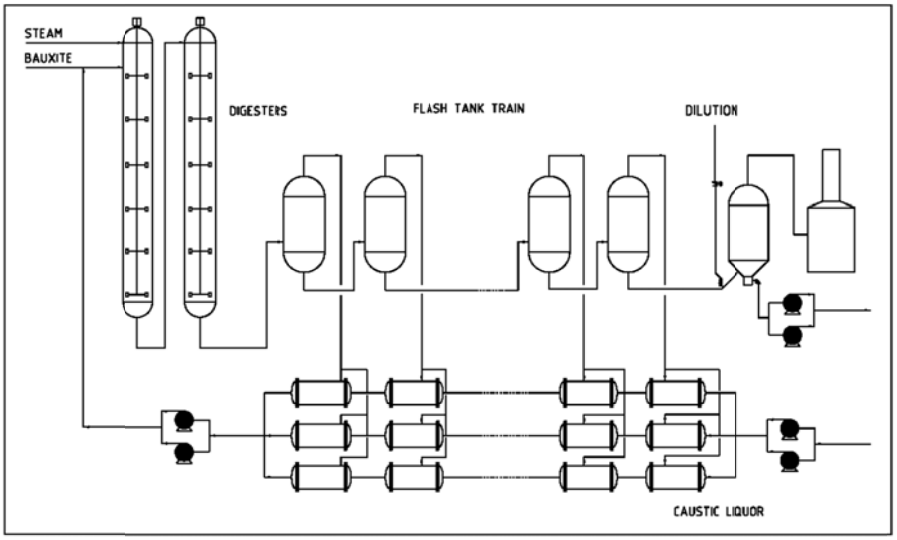

Figure 1: Dual Stream Digestion Flowsheet

1. Aluminium Oxide Stade – 0.6 Mtpa SGA 1973

In 1973, Aluminium Oxide Stade GmbH commissioned a greenfield alumina refinery using "Tube Digestion" technology (Figure 2). This flowsheet employed the use of four parallel digestion units to achieve its nameplate production capacity of 0.6 MTpa. The digestion unit employed the use of jacketed pipe heaters through which a combined slurry stream was heated continuously using recuperated flash tank heat. Final heating to the target digestion temperature of initially 260°C (and then 270°C) was via the use of indirect molten salt heating.

From 1973 to 2006, the production increased from 0.6 to 0.925 MTpa alumina.

The benefits of this digestion technology were;

- It maximised digestion temperature and therefore bauxite charge ratio. As a result, digestion flow productivity is maximised (alumina production per unit plant flow) and bauxite consumption minimised. In addition, liquor circuit evaporation through the digestion process is also maximised reducing the remaining liquor circuit evaporative load.
- It provides the best thermal match between heat source (flash tank train) and heat sink (heaters). No 'export' of recuperative flash tank energy is required.
- Single stream tube digestion with indirect heating eliminates plant liquor circuit dilution, reducing additional liquor circuit evaporative requirements, capital cost and energy consumption via reduced load (and cost) on the boiler plant.
- Gibbsite in the bauxite is digested through the low temperature heaters, with the alumina dissolution passivating the steel reducing the 'free' caustic and allowing (typically) the use of standard grades of carbon steel for the heater materials depending on caustic concentrations.
- It reduced heater cleaning frequencies from every 3 days on a rotating basis to every ~3 wks.
- It allowed the safe use of Wet Oxidation technology to reduce the build-up of organics in the liquor thereby improving liquor productivity, reducing liquor 'dead' volume and stabilising alumina particle size.

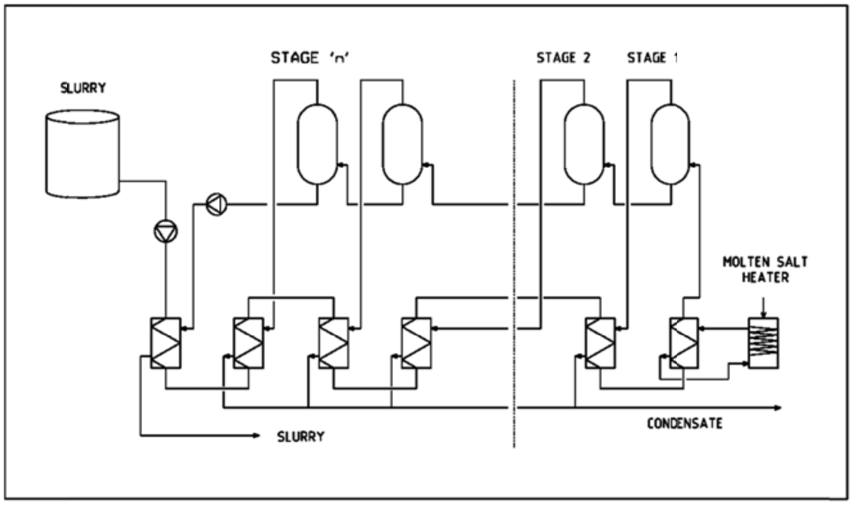

Figure 2: AOS Digestion Flowsheet - 0.6MTpa

2. Korean General Chemical Corporation (KGCC) - 1993

In the early 1990's HATCH developed multi-cell heating technology using tube digestion technology for KGCC (Korean General Chemical Company) for a refinery producing specialty aluminas. The digestion temperature for KGCC was 260°C and the plant capacity was 0.22 MTpa hydrate. Although small in capacity, it would be the pre cursor to the world's largest tube digestion plant for Comalco using this technology some 10 years later.

The patented multi-cell heating technology made the innovative step in coupling multiple heater trains to a single slurry circuit evaporator, effectively increasing three to four fold the production capacity to be extracted from a single digestion unit. Further advances allowed for the isolation and cleaning of individual heater trains within the facility.

3. Comalco Alumina Refinery – 1.4 Mtpa 2004

In preparation for the development of a new 1.4 MTpa refinery to be built in Australia employing the world's largest Tube Digestion plants, Comalco sought a collaborative partnership in suppliers of Tube Digestion technology spanning operational experience, design expertise and the latest refinery capacity improvements. A partnership between Kaiser Engineers (now HATCH), Lurgi (now Outotec) and VAW (owners of AOS at this time) was formed in 1995 to bring to fruition this refinery technology.

Based on processing Weipa bauxite, the bankable feasibility study for the Comalco Alumina Refinery concluded in early 2001. The execution phase commenced in November 2001 and process commissioning of the refinery occurred on schedule 36 months later in November 2004.
The refinery was based on two 0.7 MTpa tube digestion units with each unit using a single recuperative flash train for energy recovery and slurry pre-heat.

The single stream multi cell flowsheet is represented schematically in Figure 3 with the as built plant shown in Figure 4. In this design, the shell and tube heaters of Figure 1 are replaced by jacketed pipe heaters incorporating tubes of larger bore diameter than utilised in the shell and tube heater. Autoclaves or digesters (with internal agitators) are replaced by holding tubes providing plug flow reactor kinetics. Multiple centrifugal liquor pump-sets are replaced by single stage positive displacement slurry pump-sets which drive the slurry through the regenerative heaters to a temperature of ~ 230°C-235°C. The final heating to target digestion temperature is accomplished via indirect steam heating using high pressure boiler plant steam at 310°C and 100 Bar pressure.

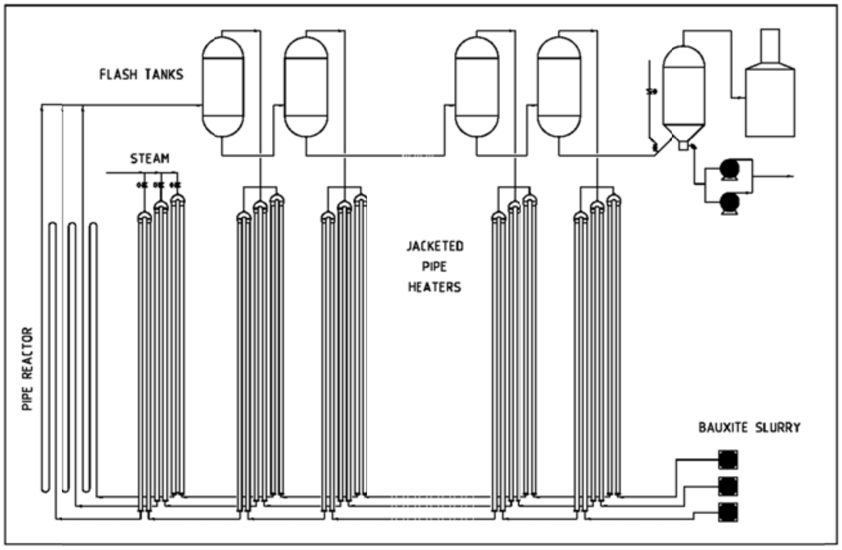

Figure 3: Tube Digestion Flowsheet

The Comalco tube digestion unit deviated from the AOS reference refinery in several significant process and mechanical design aspects. A salient summary of these are listed below:

1. Digestion temperature target selected for CAR was 280°C, relative to 270°C for AOS.
2. Unlike the AOS refinery where a single heater train is coupled to the slurry evaporator, multi-cell heating technology employing multiple heater trains was incorporated into the CAR digestion units. No fully rotatable spare heater train for cleaning outages was incorporated however. Each digestion unit capacity for the Comalco refinery was 0.7 Mtpa alumina relative to the initial 0.15 Mtpa for the Stade refinery.
3. AOS uses molten salt heating as the final heating stage allowing increased LMTD (Log Mean Temperature Difference) to be achieved by using salt up to ~ 400°C to maintain digestion unit availability. As CAR uses high pressure steam, at ~ 100 Bar pressure, a limiting LMTD is imposed by a maximum steam temperature of ~ 310°C.
4. An 8 stage flash vessel recovery circuit using external entrainment separators is used at AOS. CAR utilises 10 stages of flash recovery with no external entrainment separators.

Figure 4: Yarwun Stage 1 Tube Digestion Facility - 2004

4. Yarwun Refinery (ex Comalco) Expansion – 2.0 Mtpa SGA 2012

Rio Tinto commissioned a A$2 Billion expansion of the Comalco Alumina Refinery (now Yarwun) in 2012 to take the refinery nameplate to 3.4 MTpa SGA. The design of the refinery expansion was largely defined by replication of existing facilities with targeted facility enhancements. The brownfield expansion added a further 2.0 MTpa SGA capacity to the refinery. Incorporated into the expansion to reduce energy costs was a 160MW gas fired co-generation facility (commissioned in 2010). This comprised an electrical generator, gas turbine and heat recovery steam generator.

To accommodate the capacity increase, the digestion units incorporated:

- an additional heater train to accommodate the capacity increase
- capacity creep of each heater train
- added delivery feed pumps
- larger capacity spent liquor storage tanks
- modified back pressure system
- new vessel internals to accommodate higher throughput
- upgraded liquor, condensate and slurry circuit pumps
- upgraded instrumentation
- upgraded safety relief system capacity for the digestion units
- increased integrated spent liquor evaporator throughput and evaporation rate
- upgraded safety relief systems for the integrated evaporation unit

5. Ma'aden Alumina Refinery – 1.8 MTpa SGA 2014

The Ma'aden alumina refinery located at Ras Al Khair in Saudi Arabia (Figure 5) 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.

The selected digestion flowsheet option was 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.

To enhance facility availability, the following design features were incorporated:

- removable extraction space for the Jacketed Pipe Heaters
- sparing of the high pressure positive displacement slurry feed pumps
- sparing of the jacketed pipe heater trains
- sparing and bypass facilities for the digester vessels
- designing the digester vessels without internal agitators whilst providing required particle residence time
- duty/standby provisions for the back pressure control stations
- bypassing of individual flash tanks
- bypassing of condensate collection systems

Figure 5: Ma'aden Hybrid Tube Digestion Facility

6. Potential Second Middle East Refinery – 2.0 MTpa SGA 2017

This alumina refinery would be the second alumina refinery to be located in the Middle East. The digestion facilities (Figure 6) would operate at up to 280°C and 100 Bar pressure.

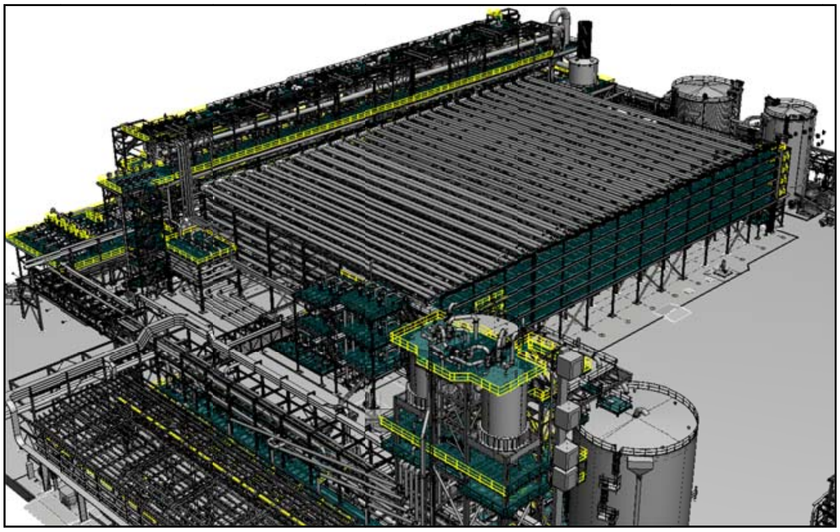

Figure 6: Second Middle East Refinery Tube Digestion Facility

The tubular digestion facilities for this refinery will offer the latest innovations in high capacity multi-cell heating. The following key advancements would be incorporated relative to the initial Yarwun refinery in 2004, some of which were implemented for the Ma'aden refinery digestion facilities:

- shared removable extraction space for the Jacketed Pipe Heaters for both digestion units
- sparing of the high pressure positive displacement slurry feed pumps
- sparing of the jacketed pipe heater trains
- standby provisions for the back pressure control station via the spare heater train
- bypassing of individual flash tanks
- bypassing of condensate collection systems
- latest flash vessel equipment design to enhance erosion resistance and minimize maintenance requirements
- latest special piping components with integral leak detection in vessel train piping to alert early life failure of erosion consumables
- improvements to materials of construction for erosion consumables to increase fitting wear life
- simplified design of slurry preheaters/condensate sub-coolers
- latest Jacketed Pipe Heater equipment design to minimize maintenance and eliminate cross flow potential between tubes
- improvements to Jacketed Pipe Heater Insulation and cladding techniques to mitigate or minimize corrosion under insulation phenomena.

7. Refinery Parameters

Table 1 below summarizes salient process parameters for the tubular and hybrid tubular digestion units above. These tube digestion refinery energy consumptions are compared against world metallurgical alumina refinery specific energy consumptions in Figure 7 [2] below.

Incorporated into these metrics is a parameter for relative liquor utilization. This liquor utilization parameter defines the volumetric flow of liquor recirculation to the digestion facility per metric tonne of alumina production.

Table 1: Key Refinery and Digestion Facility Parameters

	Process Parameter	Unit	AOS	Yarwun	Ma'aden	2nd Middle East
1	Refinery Nameplate	Tpa	0.60 now 0.925	Phase 1-1.4 Phase 2-2.0	Phase 1- 1.8	Circa - 2.0
2	Digestion Energy	GJ/t	2.7	3.2	6.1[3]	2.8[4]
3	Refinery Energy	GJ/t	7.4[1]	9.2	-	7.4-8.4[1]
4	Liquor Utilisation[2]	-	-	0.81	0.96	0.75
5	Digestion temp	°C	270	270-280	270	270-280

Notes
1 - Excludes electrical energy,
2 - Relative liquor utilization when compared to a typical dual stream flowsheet
3 - Digestion and Evaporation thermal energy after boiler house export
4 – Estimated parameters only

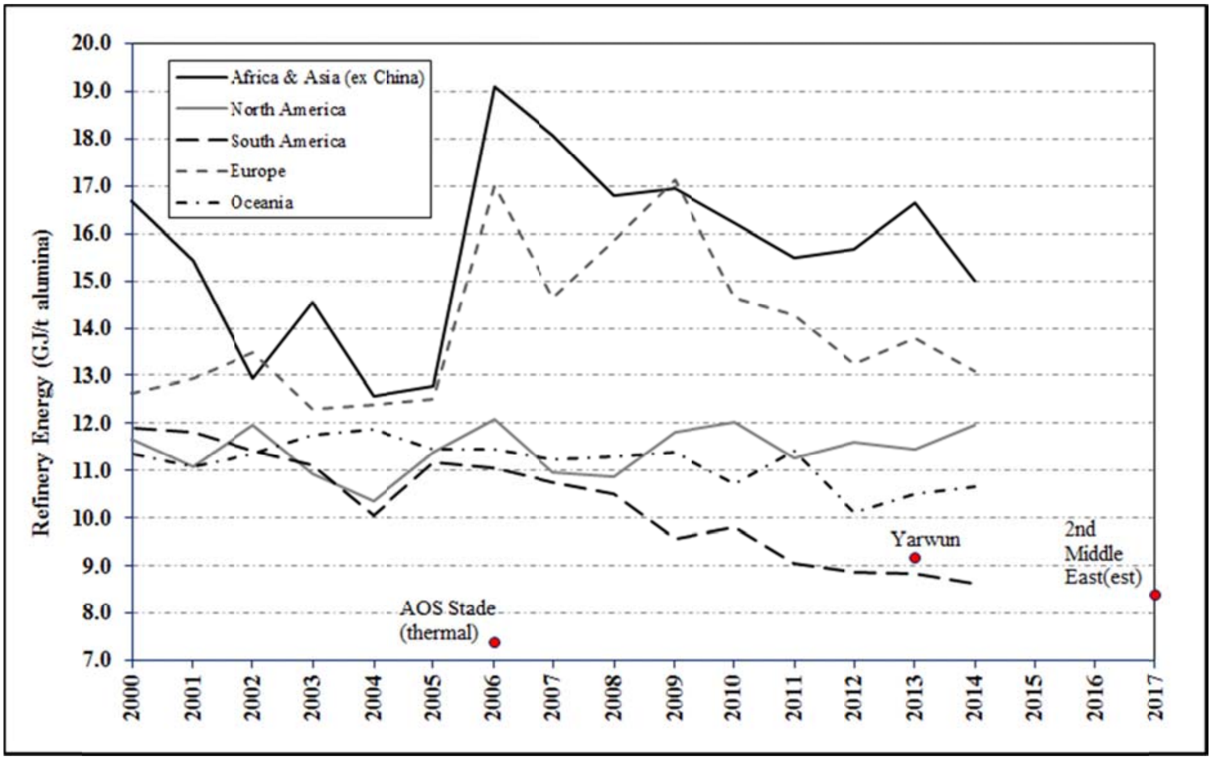

Figure 7: World Metallurgical Alumina Refinery Energy Intensity (GJ/t)

As indicated in Figure 7, the tube digestion flowsheets place these operations in the lowest quartile of refinery energy users. By comparison with the historical dual stream flowsheet used for high pressure Bayer refinery designs of the 1960's (typical refinery energy of ~ 11.6 GJ/t), the tube digestion flowsheet provides an approximate 15-20% reduction in energy use.

Accompanying this reduction in specific refinery energy consumption is a reduction in:

- spent liquor evaporative capacity
- chemical cleaning frequency of digestion facility heaters (typically every 3-9 weeks only)
- boiler plant installed capacity

- boiler facility maintenance costs
- reduction in associated utilities and chemical treatment additives for the evaporator and boiler plants.

Prior studies by Hatch [5] have estimated at least a 7% reduction in refinery installed capital cost when substituting the historical dual stream flowsheet for the tubular digestion technology.

8. Conclusions

This paper outlines the evolution of tubular digestion technology over the last half century from the 1970's through to 2016. Through this evolutionary process, economies of scale have been leveraged to maximize the benefit of tubular digestion technology to industry. The technology provides optimal energy efficiency for the high temperature refineries reducing the operating and capital costs of the digestion facility and the entire refinery. As such, it has contributed significantly to a more environmentally sustainable aluminium industry.

Resulting from these benefits, greenfield alumina refinery projects since 2001 (from Australia to Saudi Arabia and the second middle east alumina refinery) have selected this technology for their refinery flowsheets.

The challenge for the future is to find strategic opportunities to take advantage of the benefits offered by this technology and integrating it, either partially or fully, into existing plants or brownfield refinery expansions.

9. References

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