DESIGN, START-UP AND OPERATIONAL ASPECTS OF THE NEW DIGESTION PROCESS AT COMALCO ALUMINA REFINERY, GLADSTONE, QUEENSLAND

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Abstract

The Digestion section of the new Comalco Alumina Refinery in Gladstone, Queensland utilizes a new design developed in a joint venture between Kaiser Engineers, Lurgi and VAW (KLV).

Operational complexities and process inefficiencies experienced with conventional digestion plants, together with the very high pressure-temperature conditions required for a high yield and efficient alumina refinery for processing Weipa bauxite, caused Comalco to investigate a tube-in-tube heating arrangement for their Gladstone refinery project. Tube flow is essentially plug-flow and ensures a uniform holding time for bauxite heating and extraction. Other advantages include capital, operating and maintenance cost benefits.

The main problem confronting Comalco in choosing the tube-in-tube option was that most of the existing tube heating designs were conceptually limited to capacities of about 200,000 tons per annum. Comalco's alumina production target of 1,400,000 tons per annum would therefore require a multiplicity of operating units, which made these arrangements uneconomic.

An arrangement of 4 digestion units developed and operated by VAW at the AOS refinery in Germany had a total capacity of 650 000 tons per annum. Each of these units employed a single train of tube-in-tube heaters and had limited scale up potential, but VAW had the advantage of around 30 years operational experience with processing different bauxites, including Weipa bauxite. Lurgi had experience with the design and construction of the AOS refinery.

The KGCC chemical alumina refinery in Korea, completed in 1993 utilized a multiple tube heater arrangement developed and patented by Kaiser Engineers (now Hatch Associates). While the capacity of that plant was only 175 000 tons per annum, the multiple 'tube heater' design was capable of scale-up to much higher capacities.

The KLV Joint Venture between Kaiser Engineers, Lurgi and VAW was contracted by Comalco to design the new digestion system for the Gladstone project.

This paper reviews the unique design and operating solutions developed as well as the operating experiences and plant performance since commissioning of the Comalco refinery commenced September 2004.

1 Introduction

The Digestion Facility of the Comalco Alumina Refinery in Gladstone, Queensland utilises a new design developed in a joint venture between Kaiser Engineers, Lurgi and VAW.

The Comalco plant is the first large greenfield alumina refinery commissioned for some considerable time. The project had been under study for many years prior to the decision to proceed in 2001.

Process modeling and associated equipment studies indicated that for Weipa bauxite containing boehmite, the digestion temperatures needed to be as high as practicable to provide the yield necessary to render the refinery economically viable. A digestion temperature of 280°C was selected and a number of dual-stream and single-stream options for the digestion facility were investigated.

In a dual stream plant, digestion caustic liquor is heated in a counter current arrangement opposite the flash vessel train. Cold bauxite (relative to the digestion temperature) is added to the process stream at the digester (autoclave), together with injection of live steam directly into the process stream to elevate the final mixture to the required temperature. This introduces a large quantity of unwanted process dilution, rendering the design unattractive.

Experience with other high temperature dual stream digestion plants showed that heating spent liquor would be impracticable due to high silica scaling rates in liquor heaters. Since scaling rates increase with temperature, liquor heaters operating at temperatures up to those nominated by Comalco would require heater sparing that would be uneconomic and acid cleaning cycles that would be impractical.

In a single stream plant thick bauxite slurry from the grinding/desilication section is mixed with digestion caustic liquor ahead of the digestion facility and pumped through the heating section to reach the required digestion temperature. Indirect heating initially utilizes recuperative steam from the flash train followed by live steam from the high-pressure steam system. Some options directly inject steam into the process stream for the final heating step. Designs studied included several conventional shell and tube heaters and three different 'tube-heating' arrangements.

Conventional shell and tube heaters were found to be unsuitable for the temperatures required. Such heaters scale rapidly in the high temperature sections, requiring frequent acid cleaning followed by mechanical removal of hard titanate scale. Heater sizes, sparing, valving and manifolding and cleaning requirements make such a design uneconomic and impractical for the temperatures under consideration.

A tubular design originally developed by Aluturv in Hungary in which each 'tube-heater' train comprises three tubes that run the length of heater train was considered. Two tubes convey bauxite slurry while the third tube conveys spent (caustic) liquor. Tubes are switched at regular intervals with the intent that the hot spent liquor removes any scale that deposits inside heater tubes over time. In principle the idea seems attractive but will not work for high-pressure applications where acid or mechanical cleaning is required.

A tubular arrangement successfully built and operated at 270°C in Germany by VAW for more than 30 years was also studied. VAW had processed Weipa bauxite for extended periods and had accumulated operating experience and also data related to heat transfer and heater cleaning cycles. The VAW design utilized a single train of 'tube heaters' opposite each train of flash vessels.

Finally, an arrangement originally patented and designed by Kaiser Engineers and built and operated since 1993 at Mokpo in the Republic of South Korea was considered. While Mokpo is a chemical alumina plant with a capacity of only 175,000 tpa, it operates at 262°C, with final indirect heating by steam at about 82 bar. At Mokpo, a number of heater trains operate in parallel opposite a single train of flash vessels unlike the VAW design that employs a single heater train.

Following the studies, Comalco selected 'tube heaters' as the practical and economic option for the 280°C digestion temperature. Only the VAW arrangement and the Korean arrangement were operating and considered practicable at the time.

The factor that decided the arrangement finally adopted was plant capacity. Comalco required a plant capable of producing 1,400,000 tpa of alumina which was to be achieved in two separate process units capable of producing the equivalent of 700,000 tpa of alumina each. The question of whether there should be a single unit capable of 1 400,000 tpa, or two units of 700,000 tpa had been decided earlier, based on heater cleaning cycles and overall plant availability. In the final analyses the VAW arrangement did not enable scale-up above about 300,000 tpa per unit and would have required 5 separate digestion units, comprising a total of about 50 flash vessels.

The final Comalco arrangement is an adaptation of the Mokpo arrangement but incorporating VAW's operating experience processing Weipa bauxite in their tube digestion plants, as well as Lurgi experience gained from the design and construction of the VAW AOS refinery in Germany.

This paper reviews the unique design and operating solutions developed as well as the operating experiences and plant performance since commissioning of the Comalco refinery commenced in September 2004.

2 Tubular Digestion Overview

There are fundamentally 3 steps in the Bayer digestion process:

1. *Heating:* using either shell and tube heat exchangers, steam jackets inside agitated autoclaves or Jacketed Pipe Heaters (JPH's) arranged in trains.
2. *Digestion:* using agitated pressure vessels or autoclaves, or tubes (called Digester Tubes) depending on holding time requirements for alumina extraction and desilication.
3. *Flash Cooling:* using pressure vessels (called Flash Vessels).

'Tubular Digestion' refers to the whole process comprising Jacketed Pipe Heaters, Digester Tubes and Flash Vessels. JPH's may be employed in process arrangements with conventional digestion vessels.

Figure 1 : The Tubular Digestion Facility at Comalco, Gladstone, Queensland

For the new design, digestion feed liquor and bauxite slurry are mixed prior to the tubular digestion process and pumped through a number of JPH's to heat digestion feed slurry using regenerative flash vapour. Final stage heating to digestion temperature is accomplished in JPH's using live steam from a boiler. The heated digestion slurry is held at the required time and temperature in Digester Tubes to extract alumina, desilicate the digested slurry and then flashed to atmospheric pressure through a single train of flash vessels, with the flash vapour being recovered to heat digester feed slurry. Digestion emergency relief systems are designed to provide safe operation during plant upsets including power failures or pipe blockages. The design provides energy efficiency and hydraulic stability over a wide range of capacities for digestion of bauxite at temperatures of 280°C or higher.

3 Process and Technical Summary

Bauxite slurry digestion plants are subject to high rates of chemical scale deposition. In high-pressure plants, scale deposited at the high temperature end can be a hard titanate, which requires removal by mechanical means. In digester vessels or autoclaves, especially in zones of stagnation, this scale can be hundreds of millimeters thick and scale removal requires vessels be taken out of service for extended periods. The impact of such de-scaling on production is significant and requires provision of spare vessels. This in turn requires extensive slurry manifolding and valving so that individual vessels can be by-passed and isolated, adding cost and spatial requirements of the plant.

The new tubular design overcomes these problems. A typical digestion unit requires a multiple number of JPH tiers operating in parallel. JPH's are arranged in banks about 50 m long, along which the tubes are run back and forth (see above schematic). At every return bend, access is provided for high-pressure water jet cleaning. It is not necessary to clean each JPH train over its full length during each de-scaling operation.

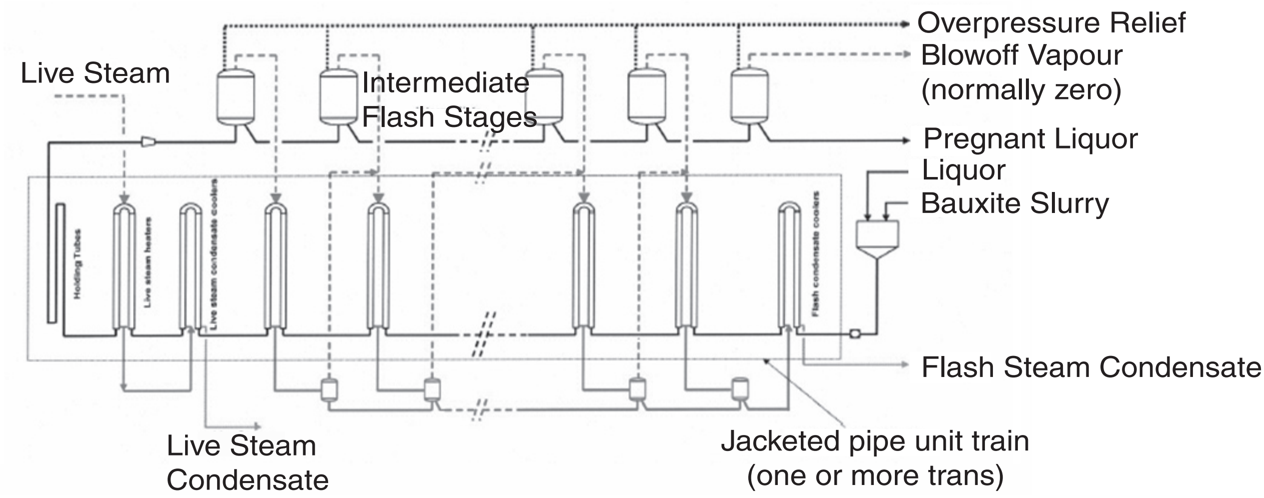

Figure 2: JPU Digestion Process Schematic

Tube sections can be accessed individually and de-scaled according to need as not all parts of a Jacketed Pipe Heater Train scale at the same rate.

Process benefits include:

- Alumina production capability up to 1,400,000 tonnes capacity per unit
- Digestion temperatures from 140–280°C with live steam heating, higher with molten salt
- Range of holding times to cater for different processing characteristics of bauxites containing boehmite, diaspore or gibbsite
- High alumina extraction efficiency with close approach to equilibrium to maximise liquor productivity
- High degree of automation due to design simplicity
- Minimum energy input
- High availability
- Low capital, maintenance and operating costs
- No direct steam injection heating employed, hence no dilution of digestion slurry occurs, resulting in reduced upstream evaporative requirements
- Natural passivation of the caustic liquor as temperature increases due to partial dissolution of alumina during the heating stages. This allows high temperature sections to be constructed of mild steel without need for protective linings or use of exotic materials.
- Thermally balanced energy streams by matching vapour consumers (JPH's) and vapour producers (Flash Vessels), eliminating the need to export flash vapour to other process areas or reject waste heat to cooling water or the atmosphere
- Cleaner flash vapour/condensate and reduced Flash Vessel scaling compared with top entry feed with similar upward vapour velocity due to use of bottom entry feeds and a managed Flash Train pressure profile. This provides optimal thermodynamic and hydraulic performance from Flash Vessels and permits an extended 12–18 month life cycle between major maintenance periods.
- Improved safety due to flowsheet simplicity and reduced labour intensity.

3.1 Jacketed Pipe Heaters

JPH design utilises thick walled 150 mm pipes rather than thin walled tubes, and hence are not subject to blockages, tube ruptures, high wear or other issues associated with traditional S&T heat exchangers. They are constructed of standard piping making them simple and cost effective to construct. A heater may contain 3 or more tubes.

Tube velocity is selected to provide best compromise between erosion, scaling rates and pump pressures. Acid cleaning frequency of even high temperature JPH's is reduced to typically every 2000 hrs. This is possible due to the relatively slow and steady degradation of Heat Transfer Co-efficient (HTC) over time. At the point of cleaning, the overall HTC of the heaters has reduced to typically 50–70% of its original 'clean' value.

Modular heater construction allows individual heaters to be mechanically cleaned as necessary, allowing an efficient cleaning program to maintain performance of the live steam heat transfer equipment. It is often the experience of refineries that the intensive labour and time taken to clean S&T heaters require a continuous 'round-the-clock' program to maintain all heaters, whereas JPH cleaning program is an infrequent event. An approximate comparison is given in the Table 1 below.

The JPH heater train design eliminates complex interconnecting slurry pipe work and a number of the valve manifolds required for S&T heat exchangers. Due to the high pressures, elimination of large 600 pound rated valve manifolds reduces capital cost, layout complexity and operating and maintenance costs associated with slurry valves and manifolds. Reduced complexity also eliminates risks of downtime and operation problems due to ongoing issues with valve passing and grinding of valves. This simplicity improves digestion availability and reliability, resulting in more consistent and increased plant production and product quality.

Since JPH trains are a simplified continuous piping system a complete train can be cleaned at one time using acid followed by pigging, significantly reducing downtime, maintenance and operating costs compared with S&T slurry heat exchangers.

3.2 Digester Tubes

In Digester Tubes the scaling problem associated with digester vessels is much less pronounced. The reduced rate of scaling and the nature of the equipment allows cleaning by standard high-pressure water jet cleaning equipment.

Alumina extraction from the bauxite throughout JPH's and Digester Tubes occurs in a flow regime that is essentially plug-flow, eliminating flow by-pass and short circuiting that occurs in digester vessels. All plant flow is therefore subject to the same residence time and the same level of extraction.

JPH tubes and Digester Tubes can be operated in parallel streams, only one of which needs to be cleaned at a time so that the impact of de-scaling operations on production is less pronounced than it is for vessels. The need for spares and by-pass facilities is eliminated.

3.3 Comalco Refinery Design

Two identical units each of 700,000 tonnes annual capacity are installed at the Comalco refinery. Each unit comprises 3 trains of JPH's that heat bauxite slurry in 12 stages. The first 10 stages use flash vapour, the 11th and 12th stages rely on live steam. Once heated in the JPH's, the slurry stream flows to the Digester Tubes to extract the remaining alumina from the bauxite. The slurry is then flash cooled through 10 stages of Flash Vessels.

4 Operating Experiences at Comalco – Overview

Since commissioning in September 2004, the plant has been mostly in a low flow transient state due to Digestion Feed Pump reliability problems. The plant has not operated at design flow. Extended periods of

Table 1 : Typical Comparison Cleaning Data for JPH's and S&T Heat Exchangers

Heater Type	Operating Temp. (°C)	Acid Clean Frequency (Hrs)	Time to Acid Clean (Hrs)	Mechanical Clean Frequency (Hrs)	Time to Mechanically Clean (Hrs)	Average Re-tubing Requirements (% Of Tubes)
JPH	<200	1500–2000	20–40	Not Required	N/A	No Re-tubing
	>200	1500–2000	20–40	4000 (HP Water Jet)	100–150	No Re-tubing
S&T HEX	<200	400–500	30–50	2000–3000 (Partial Drill/ Re-tube)	300–400	20–60% (Single Stream) 10–20% (Dual Stream)
	>200	100–200	30–50	500–1500 (Partial Drill/ Re-tube)	400–500	40–80% (Single Stream) 20–30% (Dual Stream)

half and occasionally one third design flow have occurred. Such operation causes excessive wear, particularly in underflow pipe work in the Flash Train and the Back Pressure Control (BPC) Station. Nevertheless most of the equipment, back pressure stations excepted, has proven to be remarkably forgiving of the stops, starts and associated shocks experienced from time to time.

Operation of the plant at low feed rates during extended periods also impacts scaling of the heater train due to low slurry velocity. Particularly detrimental to scaling rates is the repeated cooling and heating that occurs when pumps fail and heaters are taken off line and later started-up again. During such unintended cycles the deposited scale, while still acceptable heat transfer wise, is often dislodged and swept along to form restrictions that would normally not occur. Heater scaling rates are expected to improve considerably when the PD pump reliability problems are resolved. Slurry velocities will then increase, while temperatures will remain stable.

4.1 Digestion Slurry Feed Pumps

The positive displacement slurry pumps that feed each JPH heater train, designed to operate at 353 m^3/hr (388 m^3/hr max) continuously, have not operated to specification. Pump failures are an ongoing issue despite considerable work being carried-out:

- A centrifugal slurry feed pump installed on the suction of the PD pump plus a new pulsation dampener on the PD pump discharge did not resolve problems with pump reliability, diaphragm failures nor vibration in pipe work and have now been removed
- Since then, different pulsation dampeners specified by Comalco and a Hatch PD Pump expert have been installed on one pump allowing that pump to be operated at 99% of capacity for periods with considerable improvement in vibration
- New PD pump wet ends are being installed to increase stroke volume and reduce required stroke rate. This is expected to alleviate problems with diaphragm failures.
- A 7th PD-pump to operate as a 'distributed spare' and able to replace any of the existing six pumps is being installed to enable flows to be maintained in the event of PD pump failure.

4.2 Back Pressure Control Station

Initially, some modifications to the BPC Station was required. To accommodate the low flows, Hatch has worked with Fischer to increase valve body size to enable an improved design, while allowing the valve trim and CV to remain the same.

To prevent the valve from operating near the closed position, one of the main causes of wear, restriction orifices have been installed downstream of the valves. This has caused the valves to open from about 20% to about 50% (45°) and valve life is now 16–20 weeks. When PD pump problems are resolved and flows reach design values, these orifice plates can be increased in size or removed. Short test runs at design temperature (280°C) indicated that the normal operating position of the back-pressure valves will be about 60% open which should increase service life considerably.

Spool pieces have been redesigned to a venturi profile. The spools are interchangeable for installation upstream or downstream of the control valve, and allow machine hard facing.

Installation of a manually operated butterfly valve at the inlet to the first flash vessel has been recommended to allow for trim during reduced flow conditions.

4.3 Flash Vessel Orifice Plate & Control Valve Optimisation

Highly variable and low flows make it difficult to optimise orifice plate sizing and control valve operation in flash vessel underflow pipe work. Some control valves have operated fully closed, resulting in loss of trim control capability and preventing proper evaluation of system hydraulics. It has therefore not been possible to evaluate distribution of two-phase losses across orifice plates or control valves.

Orifice plates in flash vessel underflow pipe work have been resized for the current restricted flows. Together with a reduced control valve CV, this seems to have partially overcome the problem, insofar that the control valves in question are now modulating.

4.4 Flash Vessel & JPH Profile Optimisation

The CAR design minimizes occurrence of 2-phase flow in pipe work between flash vessels by using a proprietary bottom entry design. Formation of small quantities of vapour in flash vessel pipe work cannot always be avoided due to operational variations and within certain limits this is an acceptable part of the CAR design. The CAR design is however, different from a typical high temperature Kaiser dual stream digestion design such as utilised at QAL where two-phase flow through the underflow pipe work is a requirement to accommodate pressure drop between flash vessels. This makes the underflow pipe work at QAL essentially sacrificial leading to its higher maintenance cost.

To date at CAR, the variable and low flows and instrumentation limitations such as lack of on-line JPH temperature measurement and recording and reliable level measurement in the upper levels of Flash Vessels have restricted optimization of Flash Vessel and JPH train profiles.

Low slurry feed temperatures coupled with below design flows have at times led to a mismatch between condensing capacities of JPH's and vapour generation in Flash Vessels. This in turn resulted in flow of excess vapour through Flash Vessel underflow piping at unacceptably high transport velocities, risking significant erosion. The situation improved once orifice sizes were increased, but will remain less than optimum until the units are operating at design flows.

At low flows, orifice plates at the flash vessel entries are less effective and more work has to be done by control valves. Under these conditions, two-phase flow problems can cause wear in the CV and underflow pipe work. Low flash vessel levels have compounded this problem at times.

Despite the operating instability, a consistently high condensate quality of 65 μs/cm has been achieved. This is an significant improvement from previous designs and a good indicator of the performance of the Flash Vessels and should improve further once stable operations are achieved.

4.5 Pigging Station

While some sanding at pigging stations has occurred, it is uncertain what relative contribution has come from the periods of low flow rates experienced, or from "locking-in" the tubes during bauxite slurry flow interruptions. Some minor piping modifications have been recommended to resolve this immediate issue. It is expected that once the plant achieves normal flows, sanding out problems will be eliminated.

4.6 Heater Cleaning

Tube cleaning, especially mechanical cleaning, has not always been carried out as planned due to the excessive workload created by plant problems. Heat transfer coefficients experienced to date have varied, but preliminary data aligns well with design given the conditions, deviating no more than plus/minus 20–30%. The true situation will not be known until operations are stable.

In May 2005 the Live Steam Heaters were estimated to have up to 6 mm thick scale, which demonstrates the robust performance of the JPH design. Design allowed for up to 3.2 mm thick scale growth on tubes before cleaning was required.

As PD pump reliability improves and flows started increasing, additional mechanical cleaning is being carried out to bring heat transfer up to its full capability. Acid cleaning is currently being performed every

1400 hrs, however it is anticipated this period will extend once plant operations are stable at design flows and conditions.

5 Conclusions

Flow constraints since start-up in September 2004 have impacted performance of the Digestion Facility at the new Comalco Alumina Refinery. Increasingly promising results are being achieved as equipment reliablity and plant problems are progressively overcome. Indications are that the Digestion Facility will perform to design once flow constraints are overcome.

It was evident during the planned shutdowns in July and August 2005 that scaling in flash vessels was minimal after 8 months of operations and vessel walls were so clean no descale was required. There was no evidence of scale in flash vessel vapour lines or on the shell side of the JPH's, highlighting the benefits of the new flash vessel design.