OPTIMISING DIGESTION FLASH TANK DESIGN FOR THE ALUMINA INDUSTRY

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Abstract

The digestion unit of the alumina refinery incorporates a number of flash tanks to depressurise to atmospheric conditions a boiling three phase slurry from pressures of approximately 30 to 40 Barg for a high temperature digestion unit or 1.5 to 2 Barg for a low temperature unit. The steam released from the flash tanks is then used to preheat the incoming liquor or slurry on its passage to the digestion conditions.

Various equipment designs have been utilised for the digestion flash tank over the last half century. These can be generally categorised into top or side entry, and bottom entry. Each design, and variation thereof, seeks to attain a controlled depressurisation of the slurry such that a relatively quiescent disentrainment of the liberated steam from the boiling liquor and solids is achieved. This serves to maintain good thermal performance of the recuperative heat transfer equipment.

This paper provides a brief review of some of these equipment designs and their inherent strengths and weaknesses. A new design of flash tank developed by Hatch Associates is also presented. This new flash tank design offers the industry the collective benefits of those designs historically used without their inherent weaknesses.

1. Introduction

The digestion unit of the alumina refinery may comprise many alternate flowsheet designs, with the cost of extraction of the alumina optimised against the bauxite chemistry. Digestion flowsheets employed in the Bayer process include split stream (liquor and slurry heated separately), single stream with steam injection (liquor and bauxite slurry combined prior to heating), single stream tube digestion (no direct steam injection) and double digestion, to name a few.

The digestion unit is in practise a slurry evaporator, where the unit operations of both chemical extraction of the alumina and evaporation of the effluent stream are combined.

One common variable in these flowsheets is the equipment employed to depressurise the boiling slurry from the digestion temperature to atmospheric conditions, i.e. the 'flash tank'. The flash tank train of the digestion unit serves as the heat recovery generator, from which useful pre-heat of the incoming liquor or slurry is performed. As superheated steam (5-11°C typical) is liberated from the boling slurry through the pressure reduction effort, the less contaminated the steam, the more efficient is the heat recovery process.

The number of flash tanks employed is an economic consideration and will typically comprise 3 or 4 stages of pressure let-down for a 'low temperature' digestion plant processing largely Gibbsitic bauxite, and 8-12 stages of pressure let-down for a 'high temperature' digestion unit processing largely Boehmitic or Diasporic bauxite.

Figure 1 below depicts a typical flowsheet schematic for a split stream digestion unit where the bauxite and liquor are combined in digester vessels after separate heating of the caustic liquor stream. Following extraction of the alumina in the digesters, the slurry is then depressurised to atmosphere through the flash tank train. Steam liberated from the flash tanks is used to perform useful preheat of the incoming liquor stream via indirect heat exchange. Downstream of the digestion unit, further separation of the bauxite residue solids from the liquor is undertaken in the Clarification circuit in thickeners operating at atmospheric pressure.

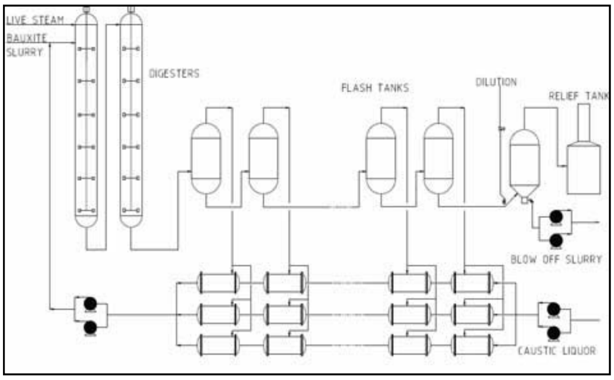


Figure 1. Digestion Flowsheet

Where the pressure ratio between upstream and downstream stages is below the critical pressure ratio, liberation of the commensurate quantity of flash steam to satisfy the mass and energy balance will typically initiate somewhere in the upstream connected slurry piping between vessels. The point of slurry incipient cavitation is often induced by a strategically located control valve or choke. The flash tank will serve the duty of disentrainment of the liberated steam from the caustic liquor and bauxite residue solids. In this condition, depressurisation or flashing of the slurry to the downstream pressure is actually near complete as the slurry (now three phases consisting of liquor, solids and steam) enters the vessel.

Where choked flow conditions prevail between the upstream vessel pressure and downstream vessel pressure, liberation of the requisite quantity of flash steam will not be complete prior to slurry discharge into the vessel, and the flash tank incurs the combined duty of steam liberation (i.e. flashing) and disentrainment of the produced steam. Regardless of fluidynamic condition, the transport of solids particles accelerated to the liberated vapour velocity is a hydraulically erosive fluid flow mechanism.

2. Side Entry Flash Tank

The side entry flash tank is depicted schematically in Figure 2 below. The side entry design of Figure 2a discharges the three phase slurry downward into the slurry pool and incorporates a minimum of piping components within the flash vessel. Unless significant staging of the upstream connected flash vessels is employed (Fig 3), slurry cavitation will commence early in the external piping and/or isolation angle valving.

As such, these designs suffer from the need for routine NDT (Non Destructive Testing) of the interconnecting piping, frequent replacement of external spools and refurbishment of the isolating valves due to premature erosion of plugs, valve stems and/or seats. In addition, the vessel disentrainment space is inefficiently utilised, as the disengaging vapour utilises only a fraction of the available vessel cyclindrical height from the point of slurry discharge to the vapour outlet, and must flow upward against the downward trajectory of the boiling slurry.

As a result of the slightly superheated nature of the produced steam and its turbulent trajectory of flow, significant vessel wall scale is generated within (typically) a twelve month campaign life for the vessel.

The vessel design of Figure 2b offers some improvement in the reduction of external piping subject to the erosive effects of slurry cavitation. Alternatively, a reduction in the upstream vessel staging to suppress external piping slurry cavitation is required, relative to the design of Figure 2a. In addition, the vapour disengagement height is improved relative to that for Figure 2a. The vapour disengagement path from the boiling slurry however, remains sub-optimal.

Figure 2 – Side Entry

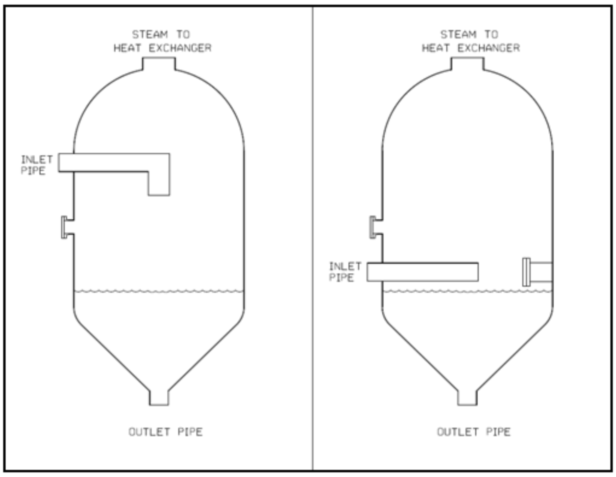


Figure 2a **Figure 2b**

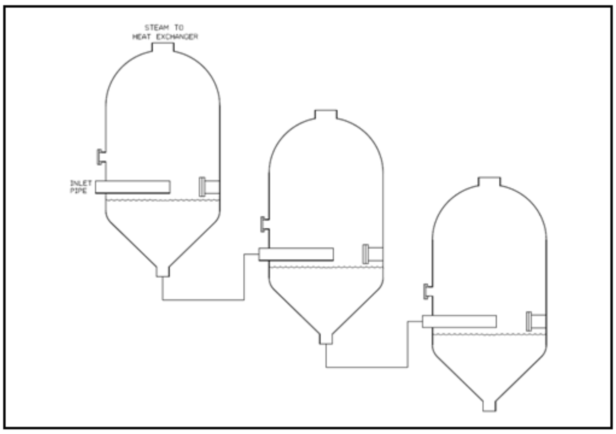


Figure 3 - Side Entry - staged vessels

Figure 3 outlines the basic elevations required for the suppression of slurry cavitation in the external interconnecting flash tank piping based on the Side Entry vessel design of Figure 2b. As the slurry within the vessel is at its vapour pressure (at the slurry/vapour interface), it is only the static head of fluid within the vessel that is available to suppress the onset of cavitation in the interconnecting piping. The three phase fluid flow pressure drop comprising static losses, frictional losses and momentum losses (acceleration) continues the solids particle acceleration throughout the piping system until the evaporation rate equates to that to satisfy the condensing capacity of the installed heat transfer equipment.

In summary, the advantages and disadvantages of the side entry flash tank design may be defined as:

Advantages:

1. Minimum of piping within the vessel requiring confined space entry for operations and maintenance personnel during vessel turnarounds.
2. External piping/fitting replacement remains relatively accessible.

Disadvantages:

1. Unless significant vessel staging is employed within the flash train, external flash tank piping will always be subject to the erosive effects of the three phase flow, requiring a continuous program of Non Destructive Testing and piping and fitting replacement,
2. A convoluted vapour disengagement path is required for the liberated steam to evacuate the vessel resulting in sub-optimal reduction of carryover of particulate into the vapour stream. This promotes premature fouling of the external heat transfer surfaces reducing thermal recuperative performance of heat exchange equipment.
3. As a result of the vapour disengagement flow path and entrained particulate in the vapour stream, significant vessel wall scale accumulates within twelve month operational periods requiring vessel outages for descaling.

3. Bottom Entry Flash Tank

The bottom entry flash tank is depicted schematically in Figure 4 below. The bottom entry design of Figure 4a discharges the three phase slurry upward into a deflection plate and into the slurry pool. With maintainment of slurry pool level within the vessel, the slurry pool assists the disentrainment duty by acting as a 'wet scrubber' eliminating a large fraction of the population of liquor droplets and particulate that would otherwise be carried upward with the disengaging vapour. With the bottom entry arrangement and maintainment of vessel slurry level, there is no need for vessel staging to suppress the onset of slurry cavitation in the upstream interconnecting piping (refer Figure 5).

The bottom entry design of Figure 4a retains a central discharge outlet for slurry flow, and introduces the two phase slurry flow (i.e. solids and liquor only at the nozzle entry point) through an internal piping tube with an internal bend to redirect the flow to the impact or deflector plate. This design maximises the useful vessel disengagement height and presents a more optimal vapour disentrainment path minimising liquor and particulate carryover.

Relative to the side entry configuration of Figure 2a, a 5 to 10 fold reduction in condensate contamination has been achieved utilising the same vessel but with a modified bottom entry piping design to that of Figure 4a. This design has significantly reduced vessel wall scaling from 300mm in thickness in less than 12 months to 25-50 mm over 18 month campaigns. Furthermore, the thermal performance of connected heat transfer equipment has also significantly improved.

The salient limitation of the design of Figure 4a remains the the internal elbow. Without further vessel staging per Figure 3, slurry cavitation will generally commence at the vessel inlet. As a result, the internal elbow is forced to turn a three phase accelerating slurry flow and incurs the erosive effects of this mechanism. Internal piping component life is therefore restricted to operating campaigns of typically 12 to 18 months.

The bottom entry design of Figure 4b eliminates the change in three phase fluid flow direction via the installation of a vertical inlet riser tube at the expense of an off-centre slurry discharge. Internal piping component life in excess of several years can be attained with this design.

Whilst this has proven to prolong the life of the internal piping, the maintainment of appropriate slurry inventory within the vessel must be monitored to ensure undue solids accumulation is avoided due to the asymmetric outlet. This, in practice, also constrains equipment operating campaigns to typically not more than 12 to 18 months.

Figure 4 – Bottom Entry

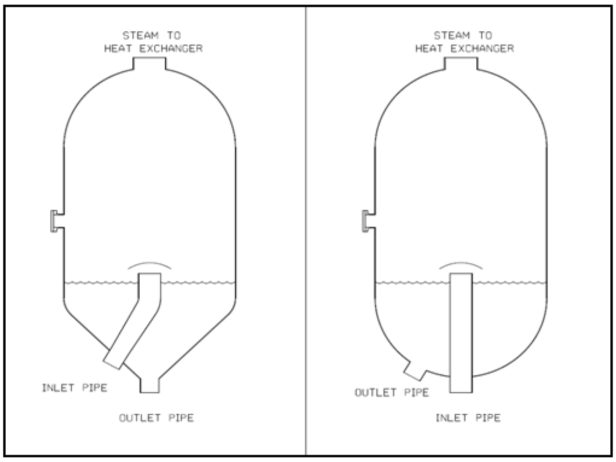


Figure 4a **Figure 4b**

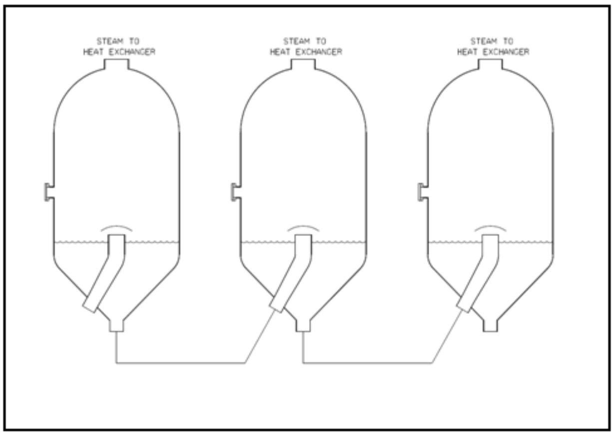


Figure 5 – Bottom Entry – Multiple Vessels

Figure 5 outlines the basic elevations required for the suppression of slurry cavitation in the external interconnecting flash tank piping based on the Bottom Entry vessel design of Figures 4a or 4b. As indicated, there is no requirement for upstream vessel staging.

In summary, the advantages and disadvantages of the bottom entry flash tank design may be defined as:

Advantages:

1. Elimination of flash tank interconnecting piping erosion and therefore significant reduction in piping/fitting maintenance time and cost.
2. Optimises vessel disentrainment capacity significantly reducing vessel wall and head scale. Also significant reduction in vapour outlet piping scale under a managed slurry inventory.
3. Improves thermal performance of connected heat transfer equipment following a 5 to 10 fold reduction in vapour contamination.
4. Mitigates the need for further disentrainment equipment.

Disadvantages:

1. Figure 4a design requires routine replacement of internal piping. Campaign life generally restricted to 12 to 18 months.
2. Figure 4b design requires vigilance in slurry inventory management to avoid excessive particle accumulation. Routine vessel bottom head descale required with campaign life generally restricted to 12 to 18 months.

4. New Design Flash Tank

A new design of flash tank has been developed by Hatch Associates that potentially offers the collective benefits of the side and bottom entry designs without the accompanying weaknesses. This new “Central Inlet Annular Discharge’ (“CIAD”) design is depicted schematically in Figure 6 below.

The slurry inlet retains the vertical upflow design of Figure 4b but retains a concentric fluid discharge via an annular outlet. Equally applicable to hemispherical or conical bottom heads, the annular discharge mitigates any eccentricity in slurry evacuation from the vessel.

The internal riser tube is designed as a prefabricated assembly to ensure ready extraction from the vessel such that confined space vessel entry maintenance related activities are minimised.

The conceptual design below has been subject to a program of analytical testing comprising:

1. Computational Fluidynamic Modelling, and
2. Physical modelling at CSIRO

Figure 6 – New Design

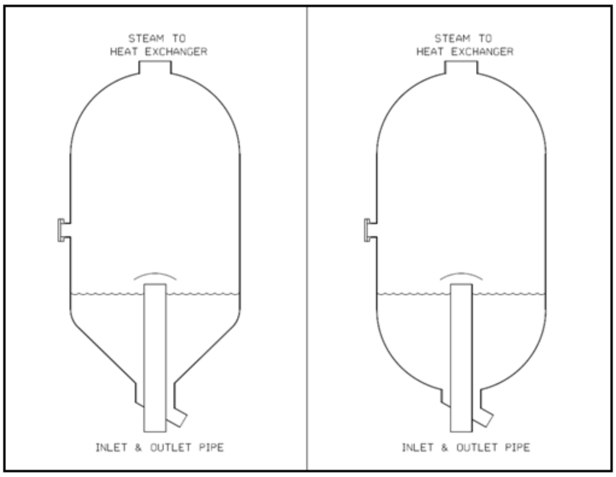


Figure 6a Figure 6b

CFD Analysis

Computational Fluid Dynamic modelling of hemispherical and conical head designs was used to confirm the viability of the annular discharge arrangement. The Euler-Lagrange approach consisting of modelling the slurry as a continuous phase and tracking the solid particles was used.

Critical to successful implementation is the annular outlet design. As the annular discharge is the critical region ensuring slurry evacuation, the geometry of the annular discharge required specific optimisation to mitigate asymmetry in velocity vectors and ensure steady and stable flow evacuation from the vessel. Following finalisation of the outlet geometry, modelling of particle streamlines over a range of solids particle sizes ranging from 40 microns to 200 microns was undertaken for both vessel geometries. Models were also run to simulate a range in slurry inventories.

As evident in Figure 7, two symmetric counter-rotational vortices are induced at the fluid discharge/vessel wall interface. These counter rotational vortices were stable and uniform for all particle sizes investigated and at both slurry inventories examined.

As discussed above, a separate optimisation at the critical annular discharge region was performed to ensure symmetrical fluid evacuation about the annulus. This included planar plots of velocity vectors at successive points along the outlet. As for the particle streamlines, the velocity vectors were stable and uniform for the range in particle sizes and slurry inventories analysed. Some small deviations were apparent for the outer section of the annular outlet (side opposite the outlet pipe), when compared to the side adjacent to the outlet pipe (refer Figure 8).

Figure 7 – New Design CFD Analysis – Particle Streamlines

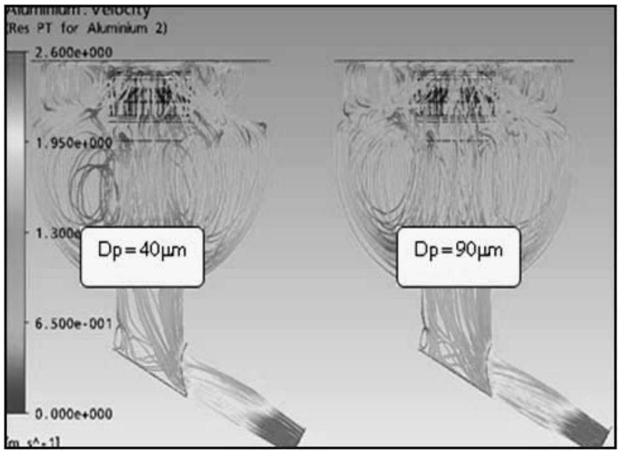
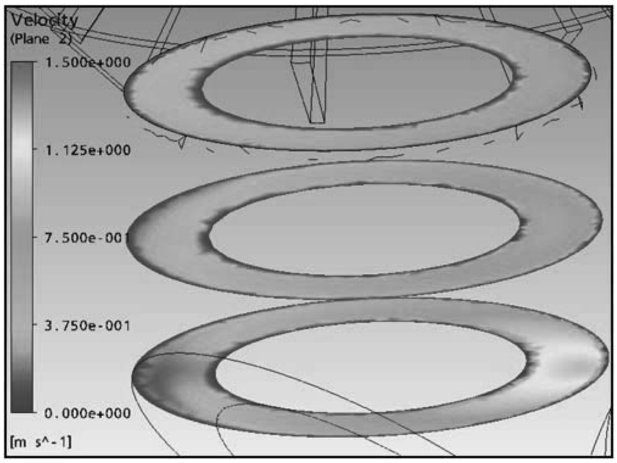


Figure 8 – New Design CFD Analysis - Velocity at Outlet



To continue the validation process, flow visualisation tests using scaled physical models with the CSIRO were then performed as outlined below.

Flash Tank Physical Modelling

Physical flow modelling was conducted in conjunction with the CSIRO (Commonwealth Scientific and Industrial Research Organisation) to validate performance data produced by the CFD analysis.

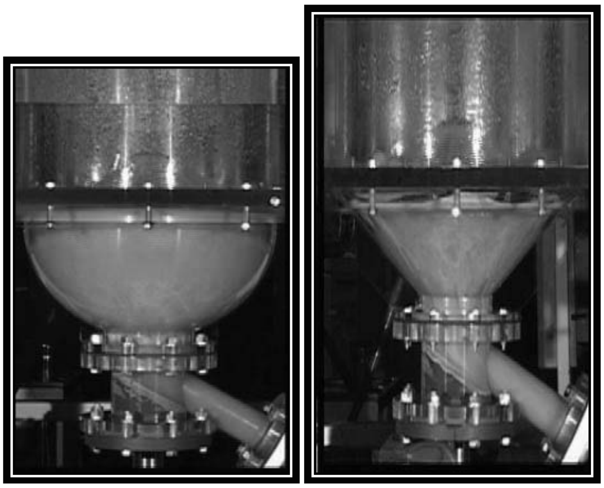
Figure 9 below shows the physical models used for the flow visualisation tests representing both hemispherical and conical head vessel designs. The models were constructed as scaled replicas of the finished vessel geometries, incorporating all piping internal support structures.

Dyed water was used for the liquor phase (representative of the liquor viscosity) and glass bead particles were used for the solids representing the required particle size distribution. Compressed air was injected into the test rig to simulate the vapour flow. Volumetric gas fractions of 88% and 95% were used to simulate high and low pressure end flash tanks, respectively.

The test models were scaled to retain the ratio of flow velocity to particle settling velocity. Although this produced a lower Reynolds number for the scaled model, the test conditions remained in the fully turbulent flow regime. Flow visualisation tests were then performed for the following conditions:

1. Hemispherical bottom head
2. Conical bottom head
3. Normal feed slurry flow
4. Minimum slurry feed flow (two thirds normal flow)
5. Low air flow corresponding to high pressure flash tank
6. High air flow corresponding to low pressure flash tank
7. High slurry level (above diffuser plate)
8. Low slurry level (50% level in bottom head)

Figure 9 – New Design - Physical Modeling



Final test runs incorporated isolating the circulating flow for a period of several minutes to allow particle settlement through the test rig and external piping and reinstating the pump flow, to gauge the ability of the system to remobilise the solids particles.

The results showed that the new design operates without formation of stationary sedimentation particles under conditions of full flow and two thirds flow, with gas fractions of 95% and 88% (to simulate a high pressure end flash tank and a low pressure end flash tank) and high level and low fluid level conditions.

Following complete isolation of the circulating flow for a period of time and reinstatement of pump circulating flow, full remobilisation of the glass beads was also observed. In particular, the critical outlet piping component demonstrated uniform and stable velocity profiles throughout the annular radius and at all vertical gradients of the outlet. This supports the observations found from the CFD analysis above.

At only one test condition was there an observed vapour lock in the test rig discharge piping. This occurred for the conical head test under conditions of almost no fluid inventory and at minimum circulation flow. This did not impede the fluid evacuation from the vessel or annular outlet. The vapour lock was displaced at the elevated slurry inventory (refer Fig 9).

In summary, the advantages and disadvantages of the Central Inlet-Annular Discharge flash tank design may be defined as:

Advantages:

1 Elimination of flash tank interconnecting piping erosion and therefore significant reduction in piping/fitting maintenance time and cost.
2. Optimises vessel disentrainemnt capacity significantly reducing vessel wall and head scale. Also significant reduction in vapour outlet piping scale under a managed slurry inventory.
3. Improves thermal performance of connected heat transfer equipment.
4. Mitigates the need for further disentrainment equipment.
5. Potential extension of equipment operation to scheduled maintenance campaigns dictated by regulatory inspection frequencies rather than component replacement.

Disadvantages:
1. Some additional complexity in vessel mating spools.

5. Conclusions.

This paper has outlined various digestion flash tank designs used over the last 50 years in the alumina industry, and the strengths and weaknesses of these equipment designs.

A new novel equipment design is proposed that offers the collective strengths of these historical approaches without the incumbent weaknesses.

This new design offers the industry a robust flash vessel design that both mitigates the frequent wear induced replacement of external and internal piping components whilst ensuring optimal vapour disengagement from the boiling slurry. In addition, a uniform and stable slurry discharge from the flash vessel is maintained at conditions of both normal plant flow and periods of plant turndown.