Impacts of Pressure Differentials between Flash Tanks on Flash Train Performance

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Abstract

The operational performance of a Bayer process digestion facility and the hence overall performance of an alumina refinery are significantly influenced by flash train design and performance. The mechanical and process design of a digestion facility must include the correct number of flash stages to match the range of operating conditions that are likely to be encountered. This will ensure the pressure differentials between flash tanks are within acceptable limits and the facility availability is high. This paper will review a number of digestion facility designs that accommodate maximum digestion temperatures across the range of 145 – 280°C. The design methodologies used to suppress the onset of three-phase flow between flash tanks (including both up-flow and down-flow designs) and the techniques used to minimise erosive wear will be discussed in detail. Finally, recommendations will be provided emphasising considerations that need to be understood when designing bauxite digestion facilities.

Keywords: Three-phase mixture velocity; wears; number of flash stages; pressure differentials.

1. Introduction

The design of a digestion multistage flash tanks and associated liquor or slurry heat exchangers must consider a number of important criteria, some of these are listed below.

- Minimise energy consumption.
- Maximise refinery productivity.
- Minimise and simplify maintenance requirements.

As the number of flash stages is increased, the amount of vapour evolved at each stage is less, but with an increased saturation temperature. Consequently, it is possible to use these smaller masses of higher grade vapour across an increased number of liquor/slurry heating stages to achieve a higher temperature prior the live steam heaters thereby reducing live steam consumption.

To identify the optimum number of flash tanks, designers must consider both capital and operating costs. A decrease in capital costs can't be consumed by an increase in energy consumption and maintenance costs. The pressure differentials between flash tanks and the hydraulic ability of the flash train must provide the required level of mechanical availability for the range of operating conditions.

2. Considerations of Number of Flash Stages

The velocity of a three-phase mixture will increase in response to an increase in the pressure drop between flash tanks and/or in the slurry flow rate. When this occurs at the low pressure end of a high temperature mineral digestion facility, the velocity can become very high because the specific volume of vapour increases dramatically as pressure is reduced.

For a given digestion facility operating under steady state conditions, the pressure differentials between flash tanks are largely governed by the number of operating flash stages and the heat transfer capacity of the associated heat exchangers. Should it be necessary to bypass a flash stage then the overall pressure drop will be taken over fewer stages with commensurately larger pressure drop per stage. This will cause an increase in three-phase velocity between flash tanks and, as a result, destructive erosion occurs if this operating mode is maintained over a long period. The heat transfer surfaces of slurry heat exchangers also foul with time, reducing heat transfer capacity, and as a result affecting the pressure differentials of the flash train. Consequently, the mechanical and process design of a digestion facility must include the correct number of flash stages commensurate with the range of operating conditions that are likely to be encountered, to ensure that the pressure differentials between flash vessels are within acceptable limits, and facility availability is high.

For a given digestion temperature and number of flash tanks the pressure differentials between flash tanks are largely fixed. Where operating conditions differ from those of the original design then the onset of destructive three-phase flow can occur. For example, Bayer process digestion facilities are often designed to operate under the following conditions:

- Flash tanks are routinely taken out of service for maintenance and the slurry is bypassed, as a result the remaining flash tanks must operate under an increased pressure differential that often results in destructive three-phase flow.
- Liquor to digestion slurry flow rates have increased beyond the rates that are associated with the original design. Friction losses between tanks are higher and a destructive three-phase flow regime can result.
- Efforts to reduce capital costs result in a reduced number of flash tanks being employed and as a consequence the pressure differentials between the installed tanks are greater and a destructive three-phase flow can occur earlier in the interconnecting pipe work.

The mechanical and process design must therefore identify the correct number of slurry flash cooling/heating stages to achieve the required heat recovery while operating with pressure differentials between flash tanks that are within the desired limits to enable acceptable performance and plant availability.

2.1. High Temperature Digestions

Performance data from nine bauxite digestion facilities, five refineries operating at temperatures between 250 – 280^{o}C and four refineries operating at temperatures between 145 - 175^{o}C are tabulated in Table 1 below. Typical Flash Tank (FT) operating pressures and pressure differentials are also listed.

The pressure differentials between the digester/holding tubes and first flash stage are particularly high for Refinery 1. Severe erosion of the backpressure control stations can be expected at the refinery.

Pressure differentials between flash tanks are high in Refinery 1 (FT-1 to FT-3) and again destructive three-phase flow can be expected to pipe works between the associated tanks. Similarly, erosive damage to pipe work between FT-2 to FT-4 for Refinery 3 can also be expected.

Despite Refineries 2 and 3 operating at an identical digestion temperature of 270^{o}C the pressure differentials under conditions of three-phase flow between flash tanks are expected to be higher for Refinery 3 than those of Refinery 2. This is because Refinery 2 employs more flash tanks

than Refinery 3. As a result, the erosive damage to the flash train in Refinery 3 is expected to be higher with consequences to condensate quality and equipment availability.

Table 1: Typical number of Flash Tanks in refineries

REFINERY		PRESSURE (kPag)						
No.	Dig.Temp (°C)	Digester/ H.Tubes	FT-1	FT-2	FT-3	FT-4	FT-5	FT-6
1	280	5260	3350	2420	1440	950	650	400
	ΔP (kPa)	1910	930	980	490	300	250	
2	270	4310	3050	2210	1680	1300	950	650
	ΔP (kPa)	1260	840	530	380	350	300	
3	270	4710	3980	3640	2510	1710	1200	890
	ΔP (kPa)	730	340	1130	800	510	310	
4	260	3890	3170	2570	2070	1590	1200	1000
	ΔP (kPa)	720	600	500	480	390	200	
5	250	2950	1990	1400	1010	750	580	440
	ΔP (kPa)	960	590	390	260	170	140	
6	175	630	340	180	100	40		1-2
	ΔP (kPa)	290	160	80	60			
7	150	380	250	160	90	40		1-2
	ΔP (kPa)	130	90	70	50			
8	145	260	160	90	40			1-2
	ΔP (kPa)	100	70	50				
9	145	250	130	50				1-2
	ΔP (kPa)	120	80					
REFINERY		**PRESSURE (kPag)**						
No.	Dig.Temp (°C)	FT-6	FT-7	FT-8	FT-9	FT-10	FT-11	BOT
1	280	440	240	140	70	20		1-2
	ΔP (kPa)	200	100	70	50			
2	270	650	440	280	190	110		1-2
	ΔP (kPa)	210	160	90	80			
3	270	890	440	140				1-2
	ΔP (kPa)	450	300					
4	260	1000	630	420	280	160	60	2
	ΔP (kPa)	370	210	140	120	100	58	
5	250	440	340	250	170	100		1-2
	ΔP (kPa)	100	90	80	70			

At the low pressure end of a flash train, pressure differentials in excess of 200kPa can also result in three-phase flow with associated erosive damage. This is due to the fact that under the prevailing conditions the specific vapour volumes are very large and as a consequence is expected to result in high and destructive localised vapour velocities. This is seen to be the case for Refinery 3 between Flash Tanks 6-7 and 7-8.

The pressure differentials in Refinery 3 can be reduced by number of options.

- Install more flash stages. This option must be reviewed against space availability in the digestion area and cost.
- A common method used to fix wear problems in flash trains without analysing the impact of destructive three-phase flow is to increase the wall thickness of piping

elements and/or hard-facing. The better method is to analyse the flash train with operated conditions before making modifications. The lifetime of pipe work depends on the thickness and hard-faced materials used.

- Move the flashing point to upstream piping (external pipe work) and gradually open the downstream pipe diameter to control three-phase mixture velocities. It should be noted that under this scenario flashing occurs outside the flash tank and therefore process safety must be carefully considered.
- Reduce the digestion temperature. This option will reduce yield, consequently to compensate for lost production, flow rate may be increased. Consideration must be given under this scenario to increased three-phase flow velocities and pumping/piping limitations.
- Modify the backpressure control stations to cater for greater pressure drop.
- A combination of the above options.

It appears that the number of flash stages in Refineries 4 and 5 in Table 1 are sufficient to minimise the impact of destructive three-phase flow on piping elements.

2.2. Low Temperature Digestion

For low temperature digestion facilities erosive damage is usually minor. Pressure differentials between flash tanks are typically low for these and consequently the flash tanks may be cascaded to provide the necessary levels between tanks, providing static head is maintained to achieve the desired flow rate.

Refineries 8 and 9 operate at an identical digestion temperature of 145^{o}C, however Refinery 9 operates with a flash tank shorter than those of Refinery 8. As a result, Refinery 9 does not have the ability to take a flash tank offline. The refinery either shuts the flash train down or operates in a manner resulting in a significant reduction in flow rate.

High pressure differentials between flash tanks must be avoided, methods used to suppress the onset of destructive three-phase flow between digestion and flash tanks are discussed below.

3. Methodologies Used to Suppress the Onset of Three-Phase Flow

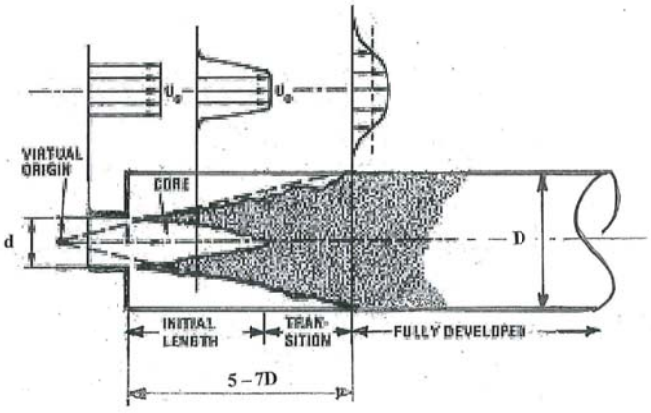

Figure 1: Velocity profile after an orifice or a nozzle.

High friction coefficient piping elements such as orifice plates or flow nozzles are usually used to create pressure losses in interconnecting pipe between flash tanks. Small ratios of the orifice

diameter to pipe diameter result in a high pressure drop across the orifice and high outlet velocities. At the onset of three phase flow, a slurry mixture requires a certain run of downstream piping to be available so that the mixture can fully develop as shown in Figure 1. The required distance depends on the magnitude of the mixture velocity and is typically within the range of 5 – 7D. This range will be increased if the ratio of the orifice diameter to pipe diameter is too small.

In general, the magnitude of three-phase velocity which causes severe wear in downstream piping elements increases from the high pressure end to low pressure end of a flash train. It depends on bauxite characteristics and designer experience.

The downstream pipe which is immediately connected to the orifice/nozzle is usually worn near the orifice/nozzle discharge area due to three-phase eddy currents and as a consequence it must be hard-faced. Any piping bend after the flashing point should also be hard-faced.

The flashing point can commence inside or outside the flash tank and the three-phase mixture can be discharged in a flash tank through either down-flow or up-flow. The type of flow is well described by Tran [2].

Flash tank elevations, the flashing point and three-phase pressure drop in each piping element can be determined by the three-phase flashing flow models (Tran, [1 and 3]).

3.1. Down-flow flash tank

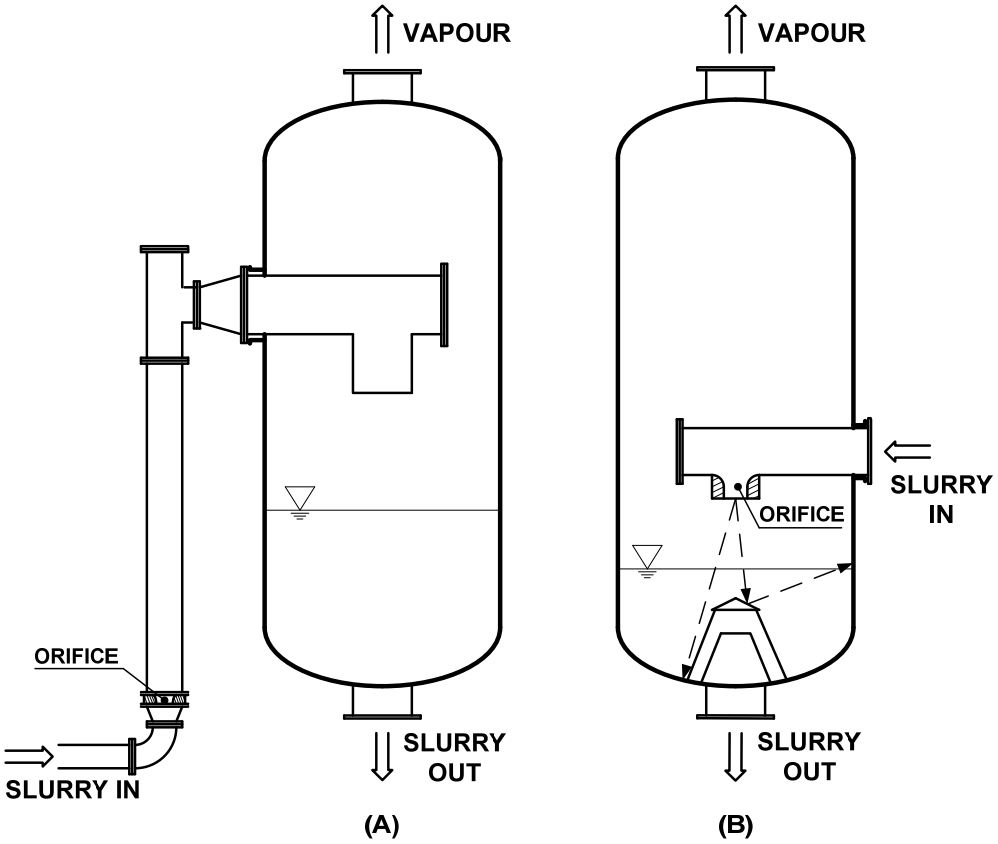

Figure 2: Down-flow flash vessels: (A) without demister, (B) with demister.

For low temperature digestion facilities, the down-flow flash tank configuration shown in Figure 2 is usually used for mechanical simplicity and the wide range of operating conditions under which it is suitable. Flashing occurs at the internal nozzle/orifice and discharges into a volume of slurry within the tank. This volume of slurry serves to protect the interior of the flash tank from erosive wears resulting from the incoming three-phase slurry mixture directly impinging on tank internals.

This piping and equipment arrangement requires that a static head be maintained between the upstream flash tank slurry level and the internal discharge nozzle of the downstream tank. This differential is necessary to overcome the friction losses in the interconnecting pipe. This type of design (Figure 2A) can also be used for high temperature digestion facilities. In this case, the flashing point occurs at the external orifice and the downstream pipe diameter is increased to control the mixture velocities. Erosive wear, due to high velocity three phase slurry mixtures, is significant in this scenario. Therefore, the thickness of external pipe work which is subjected to the three-phase flow must be monitored.

Figure 2B shows an alternative designed flash tank for high and low temperature refineries. It also requires level control to be maintained in the tank with the installation of an impact wear plate. If there is no operating level in the flash tank the incoming three phase mixture from the upstream tank will cause severe wear at the tank base, impact wear plate and side walls as shown by dashed lines in Figure 2B. This is especially true where pressure differentials are high, as is the case with high temperature digestion facilities.

3.2. Up-flow flash tank

The up-flow flash tank is usually designed to include a level control valve (butterfly or angle valve) in the interconnecting pipe work. Downstream of the control valve is an orifice or a flow nozzle through which flashing occurs allowing the level control valve to operate in slurry of single phase (without flashing).

The three-phase pressure drop between flash tanks is small in low temperature digestion facilities therefore flashing occurs inside the tank with less erosive wear. However, in high temperature digestion, the three-phase pressure drop is high, therefore the impact of high mixture velocities from the orifice or nozzle can be significant.

For a given flow rate and flash tank operating pressure the tank dimensions are determined. Tank diameter is chosen with consideration given to upward vapour velocity, while height is primarily chosen to provide volume surge and time for adequate droplet disengagement. The length of the internal feed pipe is not sufficient for the full development of high velocity three-phase mixture that originates at either the orifice or flow nozzle. This results in the incoming stream with a high “core” velocity to directly impact on downstream piping elements such as the internal elbow and witches hat (or impact plate) as shown by dashed lines in Figure 3. If the three-phase pressure drop between low end flash tanks is too high, about 300 – 400kPa, flashing is likely to occur outside the flash tank resulting in severe wear on internal piping of the flash tanks.

Operating at low flow rates (in comparison to the designed flow) the flashing point will shift to upstream piping elements, therefore flashing may occur in the control valve and/or piping elements and as a result control valve and/or piping element wear under certain operating conditions is expected.

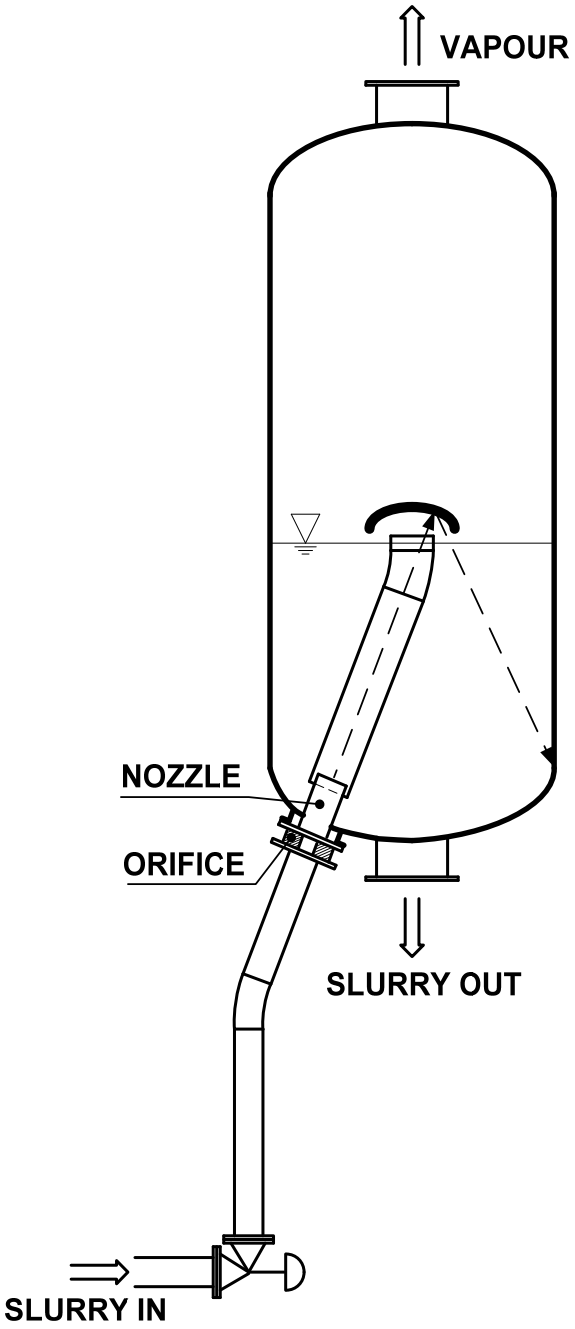

Figure 3: Up-flow and wears in Flash Tank.

4. Conclusions and Recommendations

Considering safety and minimisation of erosive damage to flash tanks, piping elements and control valves, three-phase mixture pressure differentials between flash tanks should be moderate to low so that flashing points can be designed to occur inside the flash tank. To achieve this, the number of flash stages recommended for different temperature digestions are presented in Table 2 and should be considered along with energy conservation when designing a digestion facility.

Table 2: Recommended number of flash tanks.

Digestion temperature (^{o}C)	Number of Flash Tanks	Notes
260 – 280	11 + Blow-Off Tank	+ The recommended number of flash stages will give a moderate pressure drop between flash tanks so flashing points can be designed to occur inside flash tanks to achieve the design lifetime of the flash tanks. + The recommended number of stages provides the ability to by-pass a flash tank without significant energy or flow rate loss.
250	10 + BOT	
175	5 + BOT	+ There is low three-phase pressure drop between flash tanks therefore a down-flow or an up-flow design can be selected, and flashing occurs inside flash tanks. However, consideration of flash tank elevation is one of main factors in the design. + The recommended number of stages provides the ability to by-pass a flash tank without significant energy or flow rate loss.
150	4 + BOT	
145	3 + BOT	

5. References

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