Bauxite digestion redundancy options

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Abstract

In the Bayer process, the Digestion area is usually a major contributor to plant downtime. For example many plants have an annual Digestion shutdown to clean and maintain equipment that cannot be accessed during normal operations. Since the Digestion area represents a relatively low percentage of total refinery capital cost (typically 5 to 15 %), having some redundant equipment in Digestion generally makes good business sense, since it increases the utilisation rate of the whole refinery asset. A range of different redundancy options can be found in practice. These typically employ combinations of (a) ability to bypass individual pieces of equipment and/or (b) ability to bypass "chains" of equipment in series (e.g., a row of heaters). The latter requires fewer isolation points but offers less flexibility. The optimum redundancy strategy is a trade-off between capital cost, refinery utilisation and operating complexity. This paper presents a comparison of different redundancy strategies and redundancy levels.

Keywords: Bayer process; digestion; redundancy; digestion shutdown.

1. Introduction

The Bayer process for production of alumina consists of a cyclic core process (the main liquor circuit) interconnected with a range of peripheral inputs, outputs and utility systems. Equipment outages (both planned and unplanned) in one part of the system potentially impact the surrounding operations.

The individual areas and equipment items in a Bayer refinery exhibit a wide range of reliabilities and operating cycles. Heat exchangers cleaning frequencies for example typically range between several days and several months, while precipitator cleaning frequencies may range between 8 weeks and 3 years. This diversity of operating cycles means that the concept of a whole refinery shutdown to carry out cleaning is impractical, and there are relatively few opportunities for coordinated shutdowns of neighbouring equipment.

In some cases, the material flowing from one section to another is amenable to storage, for example alumina trihydrate cake being transferred from Classification to Calcination. In such cases, a storage facility can be used to decouple adjacent operations and prevent outages in one area (in this example, Calcination) from forcing the rest of the refinery to shut down or reduce throughput.

In most cases however, the material flowing between sections is either unstable or too voluminous to allow sufficient quantities to be stored to enable cleaning and maintenance work to be carried out. This is particularly true for the Digestion area, which produces a hot, highly supersaturated slurry which must be processed with minimum delay. The quantity of slurry is approximately 10 - 15 tonnes for every tonne of alumina produced. A shutdown in the Digestion area therefore results in an almost instantaneous interruption of feed to the Clarification and Precipitation facilities. It is therefore desirable to design the digestion area for continuous operation, 24 hours per day and 365 days per year.

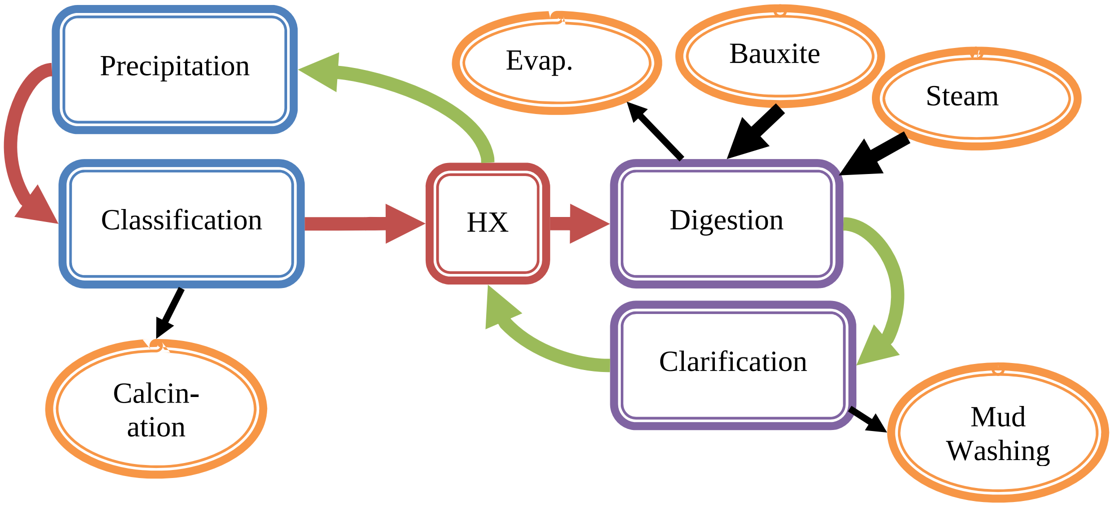

Figure 1. Bayer circuit schematic.

2. Sparing strategies

2.1 Historical perspective

The first continuous Bayer digestion units built by Alcoa in the 1930's consisted of two units operating in parallel; cleaning and/or maintenance activities required plant capacity to be reduced by half [1]. The next unit built in 1937 at Mobile incorporated bypasses of individual vessels; according to Hudson, "although the piping was complex, any vessel could be removed from service without decreasing capacity". Thus began the evolution of sparing strategies in Bayer Digestion.

2.2 Base case

The main unit operations in a typical Digestion unit are heat exchangers, autoclaves and flash vessels. This paper presents a series of sparing options configured around a base case consisting of a pump feeding through four heaters to three autoclaves, then cooling through three flash stages, which recover hot vapour to the first three heating stages. The fourth heating stage uses boiler steam.

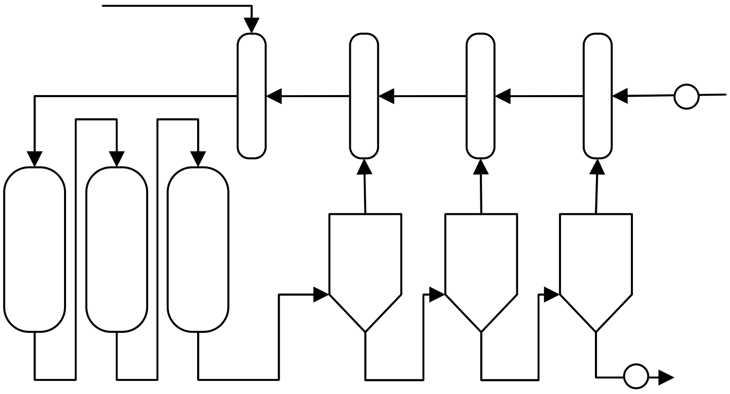

Figure 2. Base case for comparisons.

2.3. Option 1 – No sparing

Autoclaves and flash vessels typically operate between 6 months and 2 years before requiring descaling and/or maintenance. Heat exchangers require descaling on a much more frequent basis, which may vary between 5 days and 3 months depending on process conditions. If no digestion sparing is provided, then the entire digestion unit must be regularly shut down to enable the heaters to be descaled.

The impact on refinery annual production will be of the order of 10%, which generally makes this option unattractive economically. In addition, in a single-unit refinery, this option carries a significant product quality risk due to the large disruption in precipitation process conditions.

2.4. Option 2 - Individual bypasses

One way to enable equipment cleaning during continuous operation is to provide bypass valves for each individual piece of equipment. Figure 3 shows the addition of spare pumps, heaters, autoclaves and flash tanks to the base case.

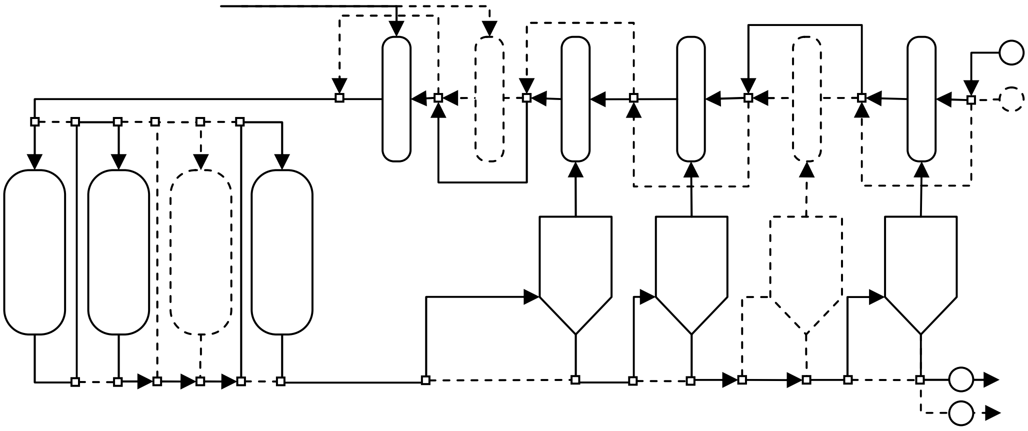

Figure 3. Individual bypass option.

The abrasive and highly scale-forming nature of the digestion slurry means that the bypass valve arrangements must use a special type of valve. Each piece of equipment to be isolated requires approximately 4 valves. For the above example, approximately 60 large-bore slurry angle valves and two steam isolation valves would be required.

Various strategies may be employed to reduce the total number of valves. For example, equipment items with long operating cycles (e.g. the first heater) may use blinds instead of valves to effect the isolation. A brief flow interruption would be required to install or remove the blinds, leading to a slight reduction in overall operating factor.

Another strategy to reduce valve count is to “pair up” units so that two successive vessels are bypassed instead of just one. This effectively halves the valve count, but may necessitate operating at reduced flow rate for the duration of the bypass.

The preceding two strategies may be combined, i.e. a pair of vessels is bypassed briefly to allow blinds to be installed to bypass one of the two vessels. The unit then only has to operate at reduced flow for the time required to install the blinds, instead of for the time required to clean the equipment.

The main disadvantage associated with this option is the high level of operator involvement to carry out isolations of equipment operating at high temperatures and pressures. The complexity of the design also increases.

2.5 Option 3 - Spare unit

The “Individual Bypass” strategy illustrated above introduces significant complexity in both design and operations. An alternative strategy is to provide an entire spare unit, as illustrated in Figure 4.

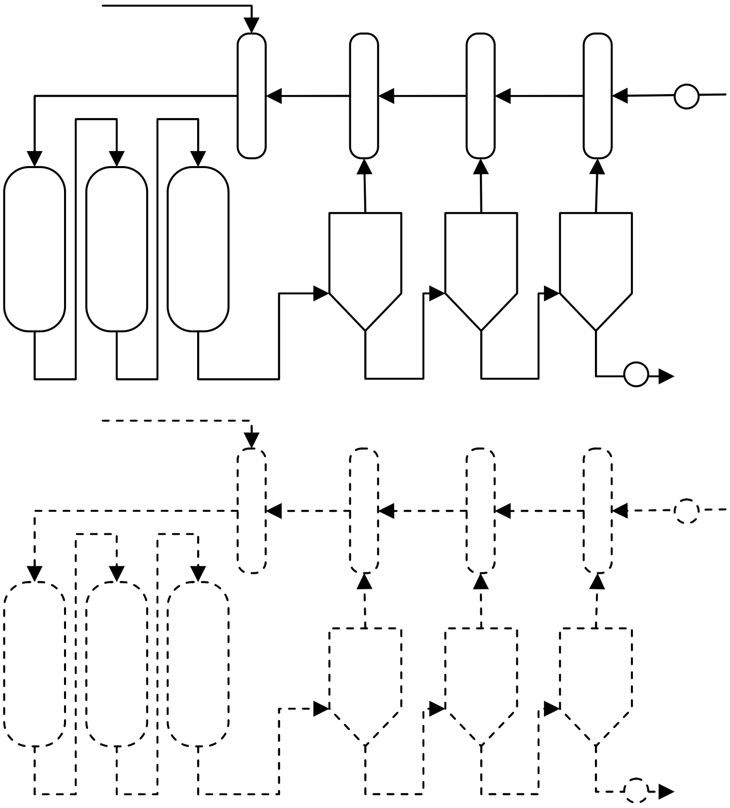

Figure 4. Spare unit option.

In this option, isolation valves are only required at the battery limits of the Unit, i.e. slurry feed, slurry discharge and steam supply. The penalty however is an increase in the number of process equipment items installed, as indicated in Table 1

Table 1. Simple equipment comparison, individual bypasses vs spare unit.

	Individual Bypass Option	Spare Unit Option
Heaters	6	8
Autoclaves	4	6
Flash Vessels	4	6
Slurry Angle Valves	~60	~ 8
Steam Isolation Valves	2	2

The comparison becomes more favourable however as additional digestion lines are added to the refinery, since only one spare unit is required.

Table 2. Simple equipment comparison, refinery expanded to two units.

	Two Units with Individual Bypasses	Two Units plus One Spare
Heaters	12	12
Autoclaves	8	9
Flash Vessels	8	9
Slurry Angle Valves	~ 120	~ 12
Steam Isolation Valves	4	3

Table 3. Simple equipment comparison, refinery expanded to three units.

	Three Units with Individual Bypasses	Three Units plus One Spare
Heaters	18	16
Autoclaves	12	12
Flash Vessels	12	12
Slurry Angle Valves	~ 180	~ 16
Steam Isolation Valves	6	4

Apart from potential cost differences, the main disadvantage of the “Spare Unit” option is that it requires heaters, autoclaves and flash vessels to all come out of service at the same frequency. While it is not necessary to descale the other vessels every time the unit comes offline, there is some risk that the thermal cycling can cause these vessels to shed scale when they come back online.

2.6. Option 4 – Spare heater train

Autoclaves and flash vessels can typically operate between 6 months and 2 years before requiring descaling and/or maintenance. Heat exchangers require descaling on a much more regular basis, which may vary between 5 days and 3 months. One option to achieve reasonable availability while keeping things simple is to provide a spare line of heaters, as shown in Figure 5. This configuration can typically operate for about 12 months continuously, followed by an extended shutdown during which all autoclaves and flash vessels are cleaned.

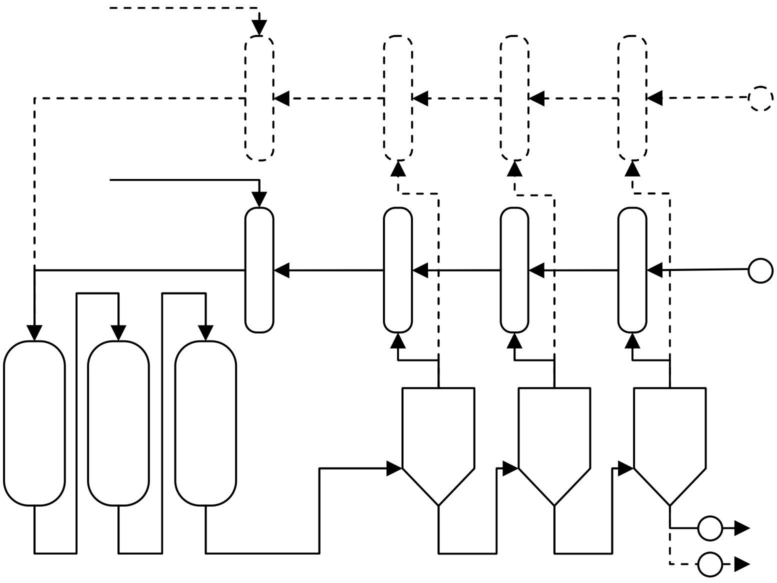

Figure 5. Spare heater train.

This extended shutdown leads to around 1 – 2 % loss in annual production relative to continuous operation.

2.7. Option 5 - Hybrid

Combining elements of options 2 and 4 to an alternative solution whereby a spare heater train is provided, while autoclaves and flash vessels have individual bypasses.

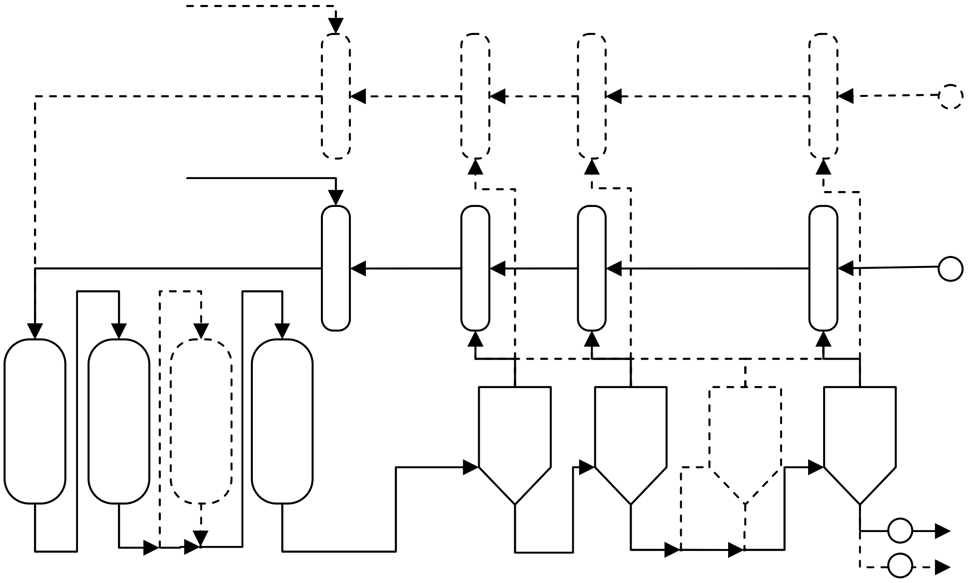

Figure 6. Hybrid option.

This hybrid option addresses the thermal cycling issues associated with the spare unit option, and reduces the number of isolations for the operators to carry out relative to the Individual Bypass option.

Table 4. Simple equipment comparison, hybrid option.

	Individual Bypass Option	Spare Unit Option	Hybrid Option
Heaters	6	8	8
Autoclaves	4	6	4
Flash Vessels	4	6	4
Slurry Angle Valves	~ 60	~ 8	~ 40
Steam Isolation Valves	2	2	~ 20
Planned Downtime	~ 0 %	0 %	~ 0 %

When a second production line is added to the refinery, the spare heater train can act as a common spare for the second line.

Table 5. Simple equipment comparison, hybrid option, refinery expanded to two units.

	Two Units with Individual Bypasses	Two Units plus One Spare	Hybrid Option
Heaters	12	12	12
Autoclaves	8	9	8
Flash Vessels	8	9	8
Slurry Angle Valves	~ 120	~ 12	~ 80
Steam Isolation Valves	4	3	~ 30

2.8. Other combinations

The examples above are far from exhaustive; it will be left to the reader to contemplate other combinations of individual bypasses, valves, blinds and trains.

3. Factors influencing optimum sparing option selection

It can be seen above that each option has positive and negative aspects. These can be amplified or diminished by a range of additional factors.

3.1. Digestion technology

There is significant interplay between digestion technology and sparing strategy.

High-temperature digestion typically has 8 to 10 operating flash stages rather than the 3 stages used in the example above. This increases the equipment “overhead” of the spare unit option, and favours spare heater trains in combination with either an annual shutdown or individual bypasses around autoclaves and flash vessels.

Dual-stream digestion, wherein liquor is heated before bauxite is added, has historically required much shorter heater operating campaigns than single-stream digestion. This is particularly so for high-temperature dual-stream digestion, where the combination of short heater cycles and a large number of flash vessels tends to favour spare heater trains combined with individual autoclave and flash vessel bypasses. Note however that the development of scale inhibitors for dual-stream digestion heaters has now led to extended heater campaigns, which means other sparing options can now be considered.

Double-digestion, which incorporates both high-temperature and low-temperature circuits, leads to a more complicated range of sparing combinations, which is beyond the scope of this paper.

3.2. Refinery capacity

For greenfield refineries with annual alumina production capacity under about 2 million tonnes, it is possible to achieve the required capacity with just one digestion unit in operation. This shifts the option analysis slightly compared to refineries above about 2 million tonnes, with more than one unit in operation.

3.3. Owner objectives

The strategic objectives of the project owner(s) have a significant bearing on sparing option selection. A high focus on simplicity and low operator numbers will tend to favour either the spare unit or annual shutdown type options. Future expansion expectations also play a significant role.

The experience and skill levels of the operators and maintainers that will be recruited to operate the new refinery can have a significant bearing on this decision.

4. Conclusion

The choice of digestion sparing strategy can have a significant influence on refinery cost and operability. The “right” selection is very much a case-by-case issue, as evidenced by the fact that, 123 years after the invention of the Bayer process, there has been no convergence towards a common solution to this challenge.

5. References

1. L.K. Hudson, Evolution of Bayer Process Practice in the United States. Light Metals 1988, pp 31–36.