Optimization of Acid Descaling Efficiency of Bayer Process Slurry Heat Exchangers

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Abstract

Low temperature digestion of gibbsitic bauxite is energy intensive, depending on heat transfer across tubular heat exchangers. At Jamalco, bauxite slurry heater performance is affected by fouling due to the presence of calcium and silica species incorporating spectator particles such as boehmite, hematite and goethite. The fouling of these heat exchanger tubes reduces heat transfer coefficients, affecting the energy efficiency of the refinery. A combination of mechanical and chemical cleaning is typically done to restore the heat transfer surfaces with inhibited hydrochloric acid being the solution traditionally used. An investigation was undertaken to study bauxite slurry-based scale removal considering adjusted blending and treatment methodologies considering inhibited hydrochloric acid and its interactions with several surface-active agents. Acid solution concentration and treatment time were also evaluated to determine impact on cleaning efficacy. It was found that a revised cleaning solution formulation of inhibited hydrochloric acid and a low dosage surfactant blend improved cleaning efficacy by more than 200 %. Cleaning efficiency was found to improve through continuous monitoring of acid concentration and subsequent re-batching based on developed concentration curves, and extended acid contact time. This paper outlines the methodology used during this experiment, the outcomes, as well as future steps to be taken.

Keywords: Chemical cleaning, Heat transfer, Optimization, Surface-active agents

1. Introduction

The optimization of energy usage during the digestion of gibbsitic bauxite is a critical element of cost reduction within alumina refineries. Species inherent to the Bayer liquor and bauxite slurry influence fouling of heat transfer surfaces. It was previously reported that sodalite fouling layers as thin as 1 mm can reduce heat transfer coefficients by 77 % [1], with estimations that 80 % of energy cost associated with such fouling is due to additional energy required to re-heat process liquor to achieve target temperatures [2].

At the Clarendon Alumina Works, fouling occurs due to two predominant factors: deviation in slurry heating design from traditional Bayer process method and the reaction, precipitation, and deposition of slurry species. It is well documented that Bayer liquor and bauxite slurry are typically independently heated in shell and tube heat exchangers prior to addition to autoclaves for the completion of the digestion process. In those processes the predominant scale specie of concern is noted to be Bayer sodalite, the reaction product of sodium aluminate and soluble reactive silica [3]. Tube digestion has presented as a modern improvement to the digestion process as it utilizes the high heat transfer efficiency of the shell and tube heat exchangers to initiate digestion within the heating step [4]. Clarendon Alumina Works, utilizes a hybrid approach, wherein, caustic concentrated Bayer liquor is mixed with bauxite slurry and then introduced to shell and tube heat exchangers, progressively heating from 86 °C to 143 °C, then heated to 148.5 °C by contact steam and passed to a bank of autoclaves. While there is appreciable improvement in the liquor alumina to caustic ratios, the heater tubes are exposed to significant foulants in the form of the undigested bauxite solids (a source of particulate fouling), and the generation of Bayer sodalite from the liquor. Further, where fouling reduces heat transfer efficiency there is also a dilution (with respects to Bayer liquor caustic concentration) penalty due to the need for direct heating via contact steam downstream to achieve the required digestion temperature.

2. Nature of Fouling and Removal Methods

X-ray diffraction analysis of heater tube fouling indicates some difference in scale type across the bank of heater. For flash steam heaters (86 °C to 112 °C) the scale was found to be composed of calcite (40 %), goethite (16 %), hematite (15 %), boehmite (14 %) and gibbsite (6 %), In the case of live steam heaters (112 °C – 143 °C), the most common species were gibbsite (23 – 47 %), boehmite (26 – 45 %) and calcite (7 – 23 %). No significant quantities of Bayer sodalite were noted in either set of heaters.

Based on scale composition, corrosion-inhibited 8 % hydrochloric acid solution has been successfully utilized to chemically descale heater tubes immediately following mechanical cleaning (hydro-blasting, drilling and polishing). However, it has been suggested that use of a surface-active agent and organic acids in conjunction with a mineral acid, could improve the descaling properties of the resulting solution by improving the wetting/contact of scale surfaces with the cleaning solution, while limiting the formation barrier layers which otherwise reduce further acid – scale reaction [5] [6]. A review of methods employed in the dissolution of similar species found in well acidizing and oil field scale removal indicates widespread use of surfactants to reduce surface and / interfacial tension, modify wettability, speed clean-up, disperse additives, break emulsions and prevent the formation of sludge [7] [8].

The effectiveness of the mechanical cleaning of the tubes, particularly drilling, was found to be dependent on visual observation. As a result, there were noted occurrences of tubes not having been drilled despite being restricted as those restrictions were not detected due to their location within the long heater tubes. Additional acid would therefore be required to remove scale in these pockets. It was previously demonstrated, in line with classical reaction kinetics, that an increase in the initial acid concentration would accelerate the rate of removal of scale [2]. However, if a limit exists on the maximum acid concentration permitted (as is the case at Clarendon Alumina Works for safety), then the rate of change of the concentration can be reduced by increasing the starting volume of acid solution.

A study of parameters that influence the efficacy of chemical de-scaling of heater tubes within the digestion unit operations of the Clarendon Alumna Works was undertaken to optimize the cleaning solution formulation and treatment methodology. The results of both laboratory and field studies are presented herein

3. Methodology

Three (3) parameters were explored for the maximization of cleaning efficiency:
Total mass of acid utilized
Cleaning time
Modification of cleaning solution chemistry
Note: fouled heater tubes chosen for the experiment were sourced from live steam slurry heaters as these were identified as being more difficult to remove based on relative hardness.

Corrosion study results indicated a loss of only 1.5 % for tube sample treated with Formulation 2 (similar to Formulation 5) versus 4.2 % loss of mass for uninhibited hydrochloric acid. Thus, efficacy of the inhibitor has been confirmed in the presence of the additive.

5. Conclusion and Further Considerations

It was found that the effectiveness of chemical cleaning of digester slurry heaters at Clarendon Alumina Works was improved by more than 200 % through inclusion of surfactants (both anionic and non-ionic) in the cleaning solution formulation. Evidence of this was noted in improved temperature pickups across heaters, heat transfer coefficients and increase mass of scale removed. Periodic or continuous monitoring of acid concentration changes during cleaning process was confirmed to be an effective method of determining extent of cleaning and the need for additional cleaning solution to tackle heavy / difficult – to - remove fouling when compared to use of fixed cleaning time intervals.

To further improve the chemical cleaning process, the following investigations would prove useful:

- Move to field trials using 75 % capacity of batching tank
- Application of lessons learnt regarding additive use to sulfuric acid-based chemical cleaning conducted on heaters of evaporator units of the refinery.
- Investigate use of additional organic acids such as acetic acid to augment cleaning in line with suggestion in literature [6]
- Conduct further investigations into the nature of fouling at T5 and T6 heaters as well as the potential impact of the extended run cycle on type and magnitude of scale formed.
- Investigations into the benefits of sweetening existing batches with fresh acid versus complete re-batching (in terms of interaction of acid and scale with impurities from past cleans) will be critical to economic viability of the approach taken to increase available mass of acid.

Acknowledgements

The authors would like to thank the Jamalco operations and technical services teams for their support in conducting this research and associated field trial. Special thanks to Remon Goulbourne and Paramount Jamaica for provision of technical support during the investigation and field trials.

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