

## UNDERSTANDING THE VALUE OF CLEANING - GAINS FROM THE USE OF ULTRASONIC CLEANING OF LARGE INDUSTRIAL EQUIPMENT

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### ABSTRACT

We present the results of a study to determine the efficacy of large-scale ultrasonic cleaning of heat exchangers at Braskem. The direct economic gains already verified due to the increase of efficiency caused by the best level of cleaning, for a single heat exchanger, were in the order of \$1.6M USD per year. We have also started to look at other systems where there is a potential for energy savings and have mapped another potential \$2.18M USD in savings thus far. Experiments to confirm these savings will proceed and yield results over the next few maintenance intervals. Furthermore, a potential hydroblasting cost reduction of \$1.1M USD was identified at the site. A less quantitative, but equally important savings is related to the large reduction in the exposure of people to hydroblasting risks, a 90% reduction in the use of water for cleaning and the associated generation of effluents and a reduction in the time for cleaning up to 50%.

### INTRODUCTION

In industrial plants, it is well understood that equipment fouling causes losses of efficiency that lead to profit reductions, either by the reduction of production levels, or by the increase of the cost of production due to the greater energy expenditure<sup>1-3</sup>. Industrial equipment cleaning solutions are, therefore, of paramount importance.

The most commonly used method today involves high pressure water blasting in many different forms – manual, semi-automated and automated. Hydroblasting, which consists of washing with a high-pressure water jet (typically in the order of 1400 bar (20kpsi), reaching in special cases up to 2800 bar (40kpsi)) is technique is of fundamental importance for cleaning activities in industrial plants, but brings with it several significant safety risks, performance limitations and environmental implications which has led us to a constant search for alternative and/or complementary solutions.

One of the key limitations of hydroblasting relates to the removal of fouling from the shell side of an exchanger tube bundle. With many tightly arranged tubes in large bundle, it is typically

impossible to completely remove all fouling, from all surfaces on the shell side of a bundle. Our experience suggests, anecdotally and through plant data, that bundles are often returned to service at less than 80% of design performance, simply due to incomplete cleaning of the shell side. This results in bundles being returned to service with (a) reduced heat transfer performance and (b) some fouling in place, which helps accelerate the future fouling once returned to service. A key question then with respect to better cleaning relates to the economic value of placing a bundle back into service after some other improved cleaning technique. Within this search for new ex-situ cleaning solutions, which included looking at chemical and pyrolysis methods, the application of the ultrasonic cleaning technique offered by the company Tech Sonic<sup>4</sup> was evaluated. The initial study led to a benchmarking visit to a company that already applied the technique, reinforcing its feasibility and earning potential. After analysis, it was decided to purchase the equipment, one of the largest ultrasonic cleaning systems available was specified at 7.7m x 1.9m x 1.9m, and a specific project was developed to evaluate the new approach and technology. The Tech Sonic method of cleaning was then applied, with excellent results, which are described herein.

### TRADITIONAL CLEANING

The default method for industrial cleaning of parts and equipment at Braskem, like most other facilities in the world, is hydroblasting and plants are equipped with “wash pads” designed for this purpose.

Because it is a mechanical cleaning technique, very thorough sweeping of the entire surface to be cleaned is required, which demands a lot of time, especially in difficult-to-remove residues and complex equipment geometries (Figure 1).

The hydroblasting technique critically depends on the impact of the water jet at high speeds with the surface, which only occurs in regions directly accessible to the water jet, see Figure 2. Thus, hard to reach areas cannot be properly cleaned, leading to performance losses and decreased equipment operation time. Our experience on the washpad



Figure 1 - Examples of hydroblasting being applied in cleaning heat exchangers

with hydroblasting suggests that badly fouled bundles are never cleaned completely on the shell side, and that a return to service at less than 80% of design heat transfer performance is common, particularly for large bundles.



Figure 2 - The space between the tubes in a heat exchanger bundle is an example of a region that is difficult to access for cleaning, especially at the inner diameter of the bundle.

It should also be taken into account that due to the high pressures involved, several pieces of more delicate composition, such as filter mesh and fractionator tower packings, for example, are damaged by hydroblasting, which prevents its use. Parts of this nature are generally replaced in their entirety.

The high-pressure water jet that causes damage to delicate parts also brings with it the greatest risk associated with hydroblasting activities: the exposure of people to potentially very dangerous energy. Various measures of control and protection are necessary to avoid accidents, which can cause serious injury and may even be fatal.

From both an environmental and cost perspective, it is also worth noting that hydroblasting activities demand high water flow rates, usually in a range of 200 to 450 litres per minute (50 – 120 gallons per minute). These high

flow rates are associated with tasks that can run for many hours up to many days, and thus lead to high water consumption and consequent generation of effluents that must be treated. A single, typical heat exchanger (6m L x 1m D, with 1400 tubes) generally will consume several million liters of water during cleaning.

## ULTRASONIC CLEANING

With so many constraints and necessary precautions, it is natural that we constantly seek alternatives to hydroblasting. Several techniques have been tested in the industry over the years, from mechanical scrapers to chemical treatments, from blasting with other media (such as dry ice) to automated and semi-automated cleaning systems.

A traditionally widely used method with great efficacy and efficiency in cleaning laboratory equipment is ultrasonic cleaning. As it is usually limited to small volumes, it is not commonly used in the cleaning of industrial equipment.

The ultrasonic cleaning technique consists of the immersion of parts in a solution subjected to ultrasonic vibration. The acoustic pressure of the ultrasonic waves leads to the formation of microcavities in the solution, also called cavitation bubbles (Figure 3). These bubbles grow rapidly and collapse violently, forming a microjet directed towards the surface. In addition to the microjet, a shock wave is formed with even larger pressures. These two combined effects impact the surface, similar to the effect of a high-pressure stream of water on a microscopic scale, and where a coating is present, as in the case of fouling, can disrupt that surface, displacing residues adhered to the metal part. The liquid solution used is generally tailored to the type of residue to be removed and can further act by chemically dissolving the residue (with the cavitation effect greatly increasing the dissolution efficiency by increasing the reaction rate) or by capturing dislodged fouling in suspension (thereby avoiding redeposition on the freshly clean surface).

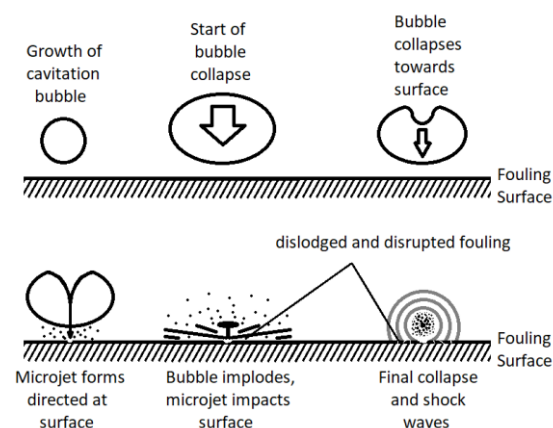


Figure 3. The mechanism of ultrasonic cleaning

Because it is a mechanical effect generated from acoustic waves present throughout the entire bath, and across all surfaces of the part, ultrasonic cleaning does not rely on surface sweeping, which dramatically reduces the time required for cleaning.

In addition, the formation of the cavitation bubbles on the entire surface of the part ensures cleanliness in all regions in contact with the solution, even those difficult to access directly. In equipment with complex geometry this can lead to great gains in cleaning quality and consequently in operating performance.

As the formation of the microbubbles is spread over the surface of the part, and individually imparts a very small, but localized energy, there is no risk of mechanical damage, which makes the technique especially useful for delicate parts.

The absence of high-pressure water jetting as the primary cleaning mechanism greatly reduces or eliminates the inherent risks of personnel exposure in hydroblasting activities.

Finally, the bath chemistry used in ultrasonic cleaning is reused many dozens of times, which drastically reduces water consumption and the need for effluent treatment.

Ultrasonic cleaning does have some limitations with respect to the type of equipment that can be cleaned. The main limitation is size – anything to be cleaned must fit completely into the bath. It is also critical to ensure that the chemistry being used in the bath is materially compatible with the equipment being cleaned. Carbon and stainless-steel equipment may be cleaned safely in most of the aqueous degreasers and organic acids proposed. Some metals, such as aluminium do provide a chemical compatibility challenge and must be handled differently from a process and chemistry perspective. It is also important that the equipment being cleaned be completely filled with the cleaning fluid as it is lowered into the cleaning bath. For some equipment this can present a challenge (such as fixed tube sheet exchangers). Finally, because the entire part is immersed in the bath, the ultrasonics may remove paint, other coatings or lubrication which is desirable to maintain.

Due to all these advantages in relation to hydroblasting and starting from the large historically proven efficiency in cleaning small parts, great effort has been applied in the development of large volume ultrasonic cleaning equipment for industrial application. The Canadian company Tech Sonic L.P. has recently developed such large-scale ultrasonic cleaning systems, capable of cleaning large industrial parts, especially heat exchangers.

This work describes the development of an ultrasonic cleaning system adapted to the needs of Braskem and the subsequent implementation of the technique, unprecedented in Latin America.

## IMPLEMENTATION

The process used for the implementation of ultrasonic cleaning is illustrated below:

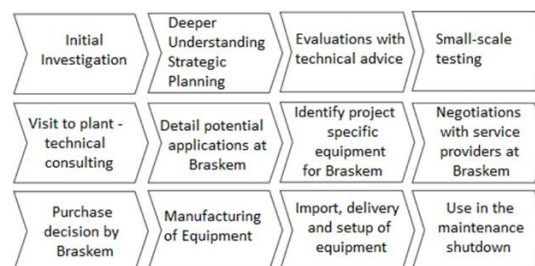


Figure 4 – Implementation Process

The initial investigations were carried out by the BA Maintenance Center team. Subsequently, the results were passed to the New Maintenance Technologies, Strategic Management of Maintenance and Reliability Group.

After a theoretical background in the technique was established, we sought the opinions of a 3<sup>rd</sup> party user of the technology as a consultant (This company has a technical service agreement with Braskem). This company reported quite positive experience with ultrasonic cleaning some of its units, and confirmed the advantages expected.

Talks were then held to use ultrasonic cleaning equipment for small parts at maintenance events at Braskem. For logistic, timing and budgetary reasons, none of the tests ever came to fruition.

With the failure to arrange smaller test cleaning, we decided to focus on a maintenance turnaround at our plant in Bahia, where there were several large exchangers that had historically proven difficult to clean. To further support this idea, a technical visit was made to a production site of the consulting company in the Netherlands, where ultrasonic cleaning was being used at such an event. This visit included understanding the practical aspects of the application of the technique, such as the use of different cleaning fluids, rinsing dynamics, immersion times, among others. The highlight of the visit was the confirmation by the user at a chemical plant that the technique was a “game changer”, due to the quality of the cleaning and consequent impact on the performance of the equipment (Figure 5).

The next step consisted of a detailed survey of the equipment to be cleaned during the turnaround in Bahia with a focus on heat exchangers (because they represented the largest fraction of cleaning service time and costs). We also looked at the cleaning history in recent years including the type and severity of fouling observed, the characteristics of the bundle (fixed or removable), the dimensions (diameter, length, # tubes), inspection reports and the cost to perform the cleaning with hydroblasting.





Figure 5. Visiting a plant in the Netherlands to verify the technique

Some of the equipment identified as having the greatest potential for ultrasonic cleaning, both for the impact on the process and for the difficulty of cleaning with conventional methods, were quench oil exchangers (one of the fluids used for cooling the effluent areas in olefin plants), shown in Figure 5. Typically, a lot of fouling is formed on the outer side of the tubes (commonly called the "shell side") of these exchangers, which significantly decreases their performance. The same situation has been identified for several other exchangers with fouling on the shell side in other areas of the plants. Due to the geometric configuration, hydroblasting cleaning is only partially efficient as it is not possible to access the tubes further towards the center of the bundle. Thus, incomplete recovery of heat transfer efficiency is observed after cleaning the equipment with hydroblasting. Our hope was that due to the nature of ultrasonic cleaning, such incomplete restoration would not be observed, and that the new cleaning method would return the performance to levels comparable to that of new equipment.



Figure 5 – Example of fouling on Quench Oil Exchangers

It turned out that none of the systems available from Tech Sonic was large enough to clean the quench oil bundles due to the large width of their tube sheets. The equipment at the time had an

internal length up to 9.75m, but an internal width of only 1.6m. This would need to be widened to 1.9m to accommodate our bundles. The survey was extended to other Braskem units, where other bundles were identified in the same situation. Since the ultrasonic cleaning bath must have an internal volume large enough to accommodate the entire exchanger, a limitation exists with this technique. Unlike hydroblasting, where "one size fits all", the ultrasonic method will be limited by the size of the bath, so it was important to consider equipment dimensions when planning to implement the ultrasonic method.

Armed with technical details about the equipment to be cleaned, we then discussed the feasibility of manufacturing a customized system to Braskem's needs with the manufacturer. Despite the relatively tight deadline, Tech Sonic accepted the challenge of designing and building the world's largest ultrasonic cleaning tank at the time.

The original strategy defined by Braskem was to contract the ultrasonic cleaning service through a Brazilian company that provides industrial cleaning services. Despite lengthy negotiations, none of the national suppliers accepted the challenge of buying the technology to provide the service in Brazil. Thus, the feasibility of purchasing the equipment directly by Braskem was evaluated.

In addition to the qualitative gains, such as lower exposure to hydroblasting risks, lower effluent generation and increased productivity in services, the main quantitative benefits expected were identified as the reduction of costs with hydroblasting and the impact on production due to better equipment performance after more efficient cleaning (increase of production and reduction of steam consumption). Considering only the gains with hydroblasting costs reduction, the return on investment would already be expected to be slightly positive. The great differential however was expected to be the earning potential due to improvements in system performance. We knew that several exchangers at least, when cleaned exclusively with hydroblasting, were returned to service at less than 100% clean on the shell side and estimated that an improvement in the shell side cleaning only would result in significant energy savings, which are applied directly to the profits of the business. These theoretical results were enough to justify the purchase viability directly by Braskem. The equipment purchase was then contracted.

The utilization strategy was then designed: the unit in Bahia, because it had a larger volume of equipment to be cleaned, would keep the equipment in routine operations and during its maintenance outages. In the maintenance turnarounds of the other Brazilian units, the equipment would be transported to each plant, returning to Bahia after each event.



Figure 6 – The first Braskem System in the manufacturing plant in Canada

The equipment was designed and built in 16 weeks, and delivery took an additional 60 days with a streamlined importation process to arrive in Bahia in September, just prior to the turnaround.

The equipment was then installed in the Braskem washpad in Bahia and put into operation, first with routine equipment released for cleaning (during normal plant operation) and then with equipment released during the turnaround (Figure 7). The results obtained are discussed in the sections below.



Figure 7 – The first bundle being placed in the ultrasonic bath in Bahia

The biggest problem we observed in implementations was simply the paradigm shift, replacing a well-established technique such as hydroblasting (despite its limitations and difficulties) with a technique unheard of in Latin America (and therefore without the experience by those directly involved). Several pieces of equipment that could have been cleaned with the ultrasonic cleaning were instead directed to the conventional hydroblasting station, under the guise of "guaranteeing cleanliness". This attitude, to a greater or lesser extent, was observed not only among hydroblasting crews, but also at times in Braskem's maintenance and planning teams.

Several issues in the operation of the ultrasonic equipment required constant attention: the need to correct the pH of the solution (not initially foreseen), the need to rinse immediately after withdrawal from the bath and the repair of damages incurred to the ultrasonic cleaning equipment itself (mainly the repair/exchange of some electronic components).

## RESULTS OBTAINED

Among the various impacts caused by ultrasonic cleaning, the most significant is related to the process gains obtained by the superior cleaning quality provided by the technique.

One of the clean bundles was that of an exchanger inserted into a butadiene production stream (BD) whose main efficiency indicator is the vapor consumption index (TS) for each ton of butadiene produced. In this process there is a contribution to the TS indicator from two exchangers. In the interval prior to the cleaning test, one exchanger had been replaced, and the other cleaned with the normal hydroblasting techniques. In the test (second) interval, the other exchanger was replaced, and the fouled unit cleaned using the Tech Sonic process. By using this approach, we are able to compare the performance over each interval and assign any gains or losses to the difference in cleaning of the similarly fouled exchangers. During the first interval (exchanger cleaned with hydroblasting), the index of that system was at 1.27 tTS / tBD. In the second interval, (after cleaning with ultrasonics), the index was verified at 0.42 tTS / tBD. This variation of 0.85 tTS / tBD represents an annual saving of \$1.6M USD in steam costs, and we assign this difference to the improvement in cleaning between the intervals for the single heat exchanger. We can furthermore point out that the performance seen post-cleaning in the second interval indicated performance of the cleaned heat exchanger that was comparable to that which would be expected if the bundle had also been replaced with a new one. Before and after photos of the butadiene process bundle are shown in Figures 8 & 9. In past cleaning, hydroblasting alone was able to remove the fouling from the tube side (I.D.) however it was apparent from visual inspection that not all fouling was removed from the shell side (O.D.) of the tubes. The incomplete removal of fouling from the shell side is common feature of hydroblasting, in our experience. The Tech Sonic process was able to remove fouling completely (as far as visual inspection could determine) from both the tube and shell sides of the bundle.





Figure 8. Butadiene fouling in the test exchanger bundle before cleaning.



Figure 9. The test bundle after ultrasonic cleaning and rinsing.

Other exchangers were mapped with high gain potential due to higher cleaning efficiency. They are components of a system of several exchangers released during normal plant operation, not as part of maintenance shutdowns. The effect can only be measured after cleaning all the system exchangers, which will take several months to occur (because the heat exchangers are released in pairs, gradually according to the plant's operating conditions). Among these exchangers are those of quench oil. The calculated value for the steam savings after cleaning of all the system exchangers is \$1.35 M USD per year. In addition, rinsing with an oil stream produced in the unit for cleaning these exchangers is now used. With the best level of cleaning from the ultrasonic technique, this oil stream could be marketed. The estimate is 500t per year, valued at \$720,000 USD.

As the cleaning cycle involves immersion in the bath and subsequent rinsing at low pressure, the need for high pressure hydroblasting is almost entirely eliminated. It still is applied in cases of tube obstruction. Overall, by applying the ultrasonic method, there was a great reduction in the exposure of people to the risks of the high-pressure hydroblasting.

The reduction of the need for hydroblasting leads of course to the reduction of expenses with hydroblasting. An initial survey pointed out that, only in Central BA, there is potential for annual

reduction of \$670,000 USD in routine services and \$425,000 USD in maintenance turnaround events.

We also noted success in cleaning other types of components. In particular, column packings and filter baskets were cleaned. A direct comparison of the results of cleaning filter baskets with hydroblasting vs. ultrasonic shows a striking difference in the ability of the method to remove fouling to the metal surface (Figure 10).



Figure 10. Cleaning filter baskets using the ultrasonic bath, and a comparison of filter baskets cleaned with hydroblasting (rear) and ultrasonics (foreground)

We also cleaned a small batch of column packings which would be impossible to clean efficiently with hydroblasting. The ultrasonic methodology was able to remove fouling from the packings with 100% effectiveness as shown in Figure 11 & 12.



Figure 11. Fouled tower packings before cleaning



Figure 12. Packings after ultrasonic cleaning.

Another significant gain was the large reduction in effluent generation. While the tank generates 32m<sup>3</sup> of effluent at each end of the campaign (which can last up to 6 months), a high-pressure hydro-blasting pump can generate 200m<sup>3</sup> per day in normal service. Considering the generation of effluents from the rinsing pump associated with the ultrasonic cleaning equipment (around 20m<sup>3</sup> per day), an approximate reduction of 90% in the generation of effluents is achieved in the services performed with the ultrasonic cleaning.

Finally, another important improvement, but difficult to measure, was the reduction in cleaning time. Due to the great variation of sizes, constructive details and residues it is complex to establish a measurable comparative number between the time required for hydroblasting cleaning and the time required for ultrasonic cleaning. Our field experience, however, makes it possible to state that ultrasonic cleaning was approximately twice as fast as conventional hydroblasting cleaning.

While the cost of ultrasonic cleaning equipment is quite high compared to hydroblasting, the return on investment is significant and fast. We have factored in only the reduction in cleaning costs and the operational savings associate with a single heat exchanger, and even so the observations suggest that the return on investment is likely significantly less than one year. It is important to consider that the technique is only applicable to removable bundles, thus the impact of better cleaning will depend strongly on the relationship between fouling impact and where the impact is – i.e. is the energy cost associate with fouling related to removable bundles, fixed bundles, or both, and in what proportion. In our experience, many of the exchangers most affected by fouling are indeed removable (partially for that reason) and we thus expect that when the improvements in cleaning efficacy are applied to all such exchangers, the return will be even larger.

#### APPLICATION POSSIBILITIES

Ultrasonic cleaning technology can be applied to all Braskem's maintenance centers, with great potential for application in several other companies with process plants. Although it cannot completely replace hydroblasting (especially for fixed bundles and for fouling incompatible with the cleaning solution), it can be considered a fundamental technology on the washpad.

As the equipment is mobile and can be transported between units, it can be used in large events such as maintenance turnarounds, and then return to the unit of origin. However, the return on investment for the installation of a cleaning system to the washpad is quite fast according to our study, less than one year, and thus the economics of ultrasonic cleaning may favour having systems

installed permanently in more than one location, to avoid the time/risks/costs associated with moving the large expensive equipment, and to make the maximum use of the system for routine maintenance activities.

In addition to the cleaning of exchanger and other equipment (such as filters, tower trays, compressors components, etc.), the great potential of the technique for cleaning small parts, such as packings of vessels and towers, bubble, etc. should be emphasized. Usually these parts are damaged by hydroblasting must be replaced every maintenance cycle. The possibility of cleaning would avoid not only replacement costs but also the need to dispose of contaminated waste. As an example, we can mention the planning of a turnaround at a Braskem unit, which provides for the ultrasonic cleaning of 65m<sup>3</sup> of random tower packings. If new fillings had to be purchased, the cost would be around \$190,000 USD.

Of course, there are several other application possibilities that have not yet been tested, which will arise with the intensification of the use of the equipment. In short, it is necessary to change the current cleaning paradigm, always considering ultrasonic cleaning, leaving for hydroblasting only when the former is not feasible.

#### CONCLUSION

As a result of the experiences with ultrasonic cleaning, and the economic benefits established in the analysis of even a single heat exchanger at the site in Bahia, Braskem has now purchased a second Tech Sonic cleaning system, which was delivered at the end of 2018. This new system is currently entering use at another Braskem plant, and subsequent cleaning experiences and results will be detailed further in the future.

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