

## FROM PRACTICE-TO-THEORY-TO-PRACTICE: ADVANCES IN THE CLEANING OF HEAT EXCHANGERS USING ULTRASOUND.

B. Kieser<sup>1,2</sup>, A. Goode<sup>2</sup> and R. Phillion<sup>2</sup>

<sup>1</sup> [byron.kieser@techsonic.ca](mailto:byron.kieser@techsonic.ca)

<sup>2</sup> Tech Sonic Services, 7550 Hwy 27, Unit 1, Woodbridge, Ontario, Canada, L4H0S2

### ABSTRACT

The cleaning of heat exchangers, and other large process equipment, using large-scale ultrasonic systems has, in the past few years, progressed from a “curiosity” to a proven, practical tool for many clients. Research and a greater understanding of the physics involved in the cleaning process and the practical considerations of operating in the field have led to improvements in design and usability.

### INTRODUCTION

Tech Sonic Services have been cleaning industrial components with large scale ultrasonic baths for over 10 years. Unfortunately, there is no industry standard definition of “Clean” thus we strive to bring every heat exchanger back to “like new” heat transfer performance – and at the very least exceed historically achieved results. Beginning in 2009, Tech Sonic began testing systems to clean large heat exchangers in the Oil Sands region in Canada. Equipment in this region is characterized by ubiquitous and extremely persistent bituminous foulants; generally mixtures of hardened polymers and catalysts (Phillion et al 2011), scale (Cho and Liu 2000), aggregate, heavy oils and asphaltene. Fouling on the surfaces of heat exchangers can greatly reduce heat transfer efficiency [Pan et al 2012]. This ultimately reduces production, and increases energy consumption as well as increasing the pressure losses, chemical and cleaning costs (Pan et al 2012). Since 2010, Tech Sonic Services has been offering ultra-large scale ultrasonic cleaning systems for heat exchangers on refinery and chemical sites throughout North America, and now in Europe.

Ultrasonic cleaning is not a new technique, and a review of the history and technology is beyond the scope of this paper. In recent years, there has been an increase in the application of ultrasonic cleaning to small heat exchangers and other related parts using traditional small industrial ultrasonic baths. Beyond cleaning, ultrasound has been proposed as a means of fouling abatement for certain types of foulants (Legaya et al, 2013) and as a means of improving heat transfer characteristics during operation (Legaya et al, 2012).

Our goal in the research and development department is to address key usability and efficiency factors related to cleaning heat exchangers with ultrasonic energy. The purpose of this paper is to describe in detail some of the

current research activities, the impetus behind those activities, and how these activities are affecting the design of new systems.

### HEAT EXCHANGER CLEANING BY ULTRASOUND

It may be a bit misleading to propose that we clean exchangers with ultrasound – it may be considered more correct to say that the use of the ultrasonic cleaning vessel greatly enhances the cleaning efficiency and effectiveness of standard hydroblasting techniques. To illustrate this, consider the “standard” approach to cleaning that is employed by Tech Sonic Services using one of our systems:

1. Inspection and rinsing of the heat exchanger: the heat exchanger is thoroughly rinsed using hydroblasting techniques to remove any loose foulant, determine if there are blocked tubes, and permit better inspection of the fouled exchanger.
2. Opening of blocked tubes: if blocked tubes are discovered during Step 1, these will be opened using high pressure lancing of some variety, depending on the nature of the foulant and the geometry of the exchanger.
3. Ultrasonic cleaning: the exchanger will be immersed in the bath for a period of time – the duration of which depends on the specific foulant/exchanger combination. In some cases, this step may precede Step 2 if it is suspected that the warm ultrasonic bath will aid in or even accomplish the opening of blocked tubes.
4. Rinse and rotation: The exchanger is removed from the bath, rinsed and rotated to remove loosened foulant, and inspected for cleanliness.
5. Step 3 and 4 are repeated until the exchanger is cleaned.

The above procedure shows that the use of ultrasonic cleaning systems does not replace, but rather greatly enhances the standard techniques. Exchanger cleaning that previously took days may routinely be accomplished in hours, with far superior results.

The use of a large-scale ultrasonic bath significantly reduces the amount of hydroblasting required and subsequently the amount of waste water generated. The review study conducted by Cho and Liu (2000)

demonstrates the large volumes of waste water being produced as a result of hydroblasting. The penetration of ultrasound into the bundle loosens, removes and/or dissolves foulant by the action of cavitation bubble collapse, the induction of shear forces between the foulant and the substrate, and the disruption of a diffusive layer at the surface of the foulant (Naude and Ellis 1961; Shima et al 1961; Kieser et al 2011). In almost all cases, the results are significantly better than those that can be obtained with hydroblasting alone.

Despite the success we have seen with the technique, we strive to improve the overall process by addressing some key areas for improvement, namely:

1. Improving the ultrasonic power distribution within the fluid
2. Improvement of foulant release within the ultrasonic system
3. Reduction of the chemistry volume required for cleaning

The objective of addressing the above three factors is to increase the efficiency of cleaning (faster) while at the same time improving the results and lowering the overall cost (less chemistry, less hydroblasting, less waste water)

In addition to the parameters mentioned above, chemistry selection is critical, and while we continue to enhance our understanding of how the chemistry works to aid in cleaning, this topic will not be included in this discussion.

### LESSONS FROM THE FIELD

The following figures serve to illustrate the need for research to address the three factors mentioned above.

Figure 1 shows a close up photo of a set of heat exchanger tubes that have been partially cleaned using an ultrasonic bath. Evident in the photo are colour bands on the tubes, which indicate an uneven concentration of ultrasonic power as the corrosion on the bundle is not completely removed from all areas of the pipe evenly.

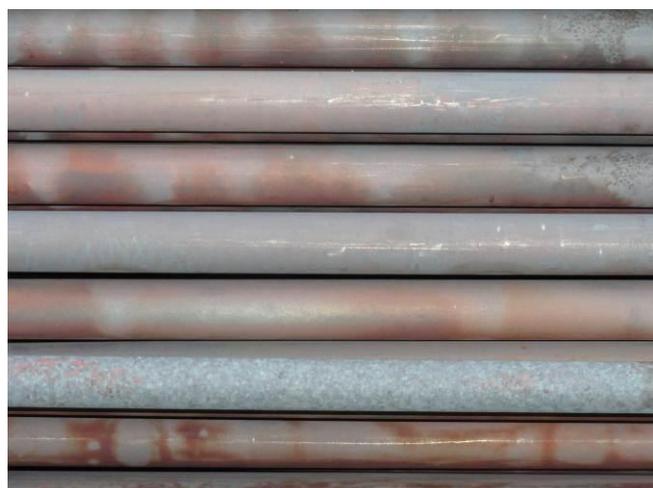


Fig. 1. Heat exchanger tubes in the process of being cleaned using an ultrasonic bath.

Figure 2 shows a good example a heat exchanger with significant foulant caught in the interstitial spaces of the bundle. Foulant that is trapped this way requires a great deal of in-process rinsing to effectively remove, and to break down the foulant such that it is able to exit the bundle through space between tubes.



Fig. 2. A fouled straight-tube exchanger with significant fouling between the tubes.

Figure 3 shows a typical exchanger being loaded into the system for cleaning. This picture serves to illustrate the manual handling involved and the large volume of chemistry required (this particular system has a volume of over 40,000 litres).



Fig. 3. A typical exchanger being removed from the ultrasonic bath for inspection and rinsing.

### EXPERIMENTAL

In order to better understand the distribution of energy in the fluid, we have attempted to make measurements of the energy field in the vessel. A hydrophone (Bruel & Kjaer 8103) was used to try and manually measure the power density distribution in a small test vessel in the lab. Ultrasound can be detected acoustically using a hydrophone by recording the changes in pressure in the liquid medium (Herbert and Caupin 2006) during sonification. The pressure changes are in the form of voltage signals (Witte et al 2008), which displays the sinusoidal amplitude of the ultrasonic propagation. We found quickly that the process

does not lend itself well to a manual approach as it is extremely time consuming and the positional accuracy is not sufficient to resolve features on the order of a few cm repeatedly. The data did however clearly demonstrate the composite ultrasonic and cavitation signal as shown in Figure 4.

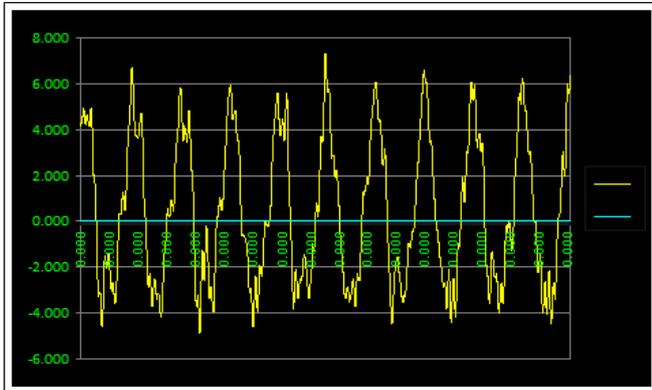


Fig 4. The ultrasonic field measured at a point in the vessel showing the 25kHz signal overlaid with the signals from cavitation bubble collapse. The x-axis is a measure of the hydrophone signal amplitude in mV. The y-axis is a measure of time in  $\mu\text{s}$ . The “jagged” signal at the bottom of the wave troughs shows the cavitation bubble collapse during rarefaction.

A model was developed to mathematically simulate the field in a plane of the tank to help evaluate the sensitivity of the energy distribution to transducer positioning and phase

$$f(x) = \Sigma \left( \frac{\sin \left( \left( \frac{\sqrt{((y_1 - Tr_1)^2 + (x_1^2))}}{\lambda m} \right) - \theta \right)}{\left( \sqrt{((y_1 - Tr_1)^2 + (x_1^2))} \right)^{\alpha_{tr}}} * m_{tr1} \right)$$

Where:  $y$  = an arbitrary point in the y direction  
 $x$  = an arbitrary point in the x direction  
 $Tr$  = location of a transducer  
 $\theta$  = phase angle  
 $\lambda m$  = wavelength multiplier (for scaling)  
 $\alpha_{tr}$  = transducer attenuation factor  
 $m_{tr}$  = transducer relative intensity

This simple finite element model provides an approximation of the field strength at any point in a plane by summing the contributions of multiple transducers to the field intensity at different points in the plane. This model makes two assumptions; first is that each transducer is considered a point source, and the second is that we could vary the attenuation between 0, linear and  $r^2$  to allow better visualization of the interference patterns. The model output is a plot of the ultrasonic energy (pressure) in an instant in time. Figures 5 (a), (b) and (c) show some 3D modeling results for three different cases of inter-transducer phase relationships. It is important to note that the point source transducers are located to the right of the plot. Each plot represents an arbitrary instant in time (the model is in fact timeless). The blue-purple colours indicate an area of high

pressure, and the green-red colours indicate an area of low pressure.

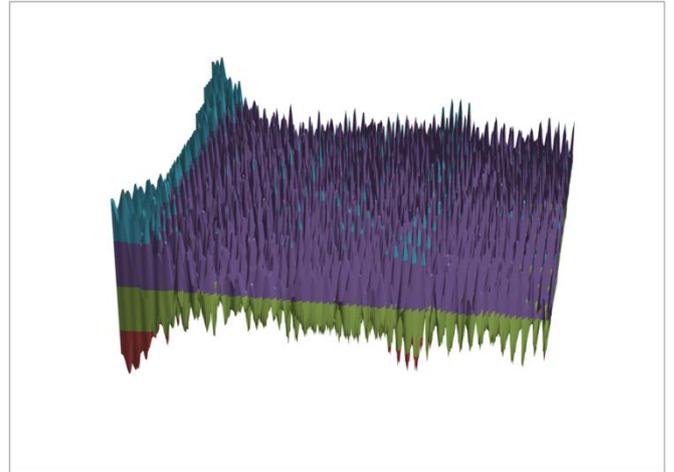


Fig. 5 (a) 11 Transducers, spaced at 4 wavelengths, with 0 phase angle, 3D plot

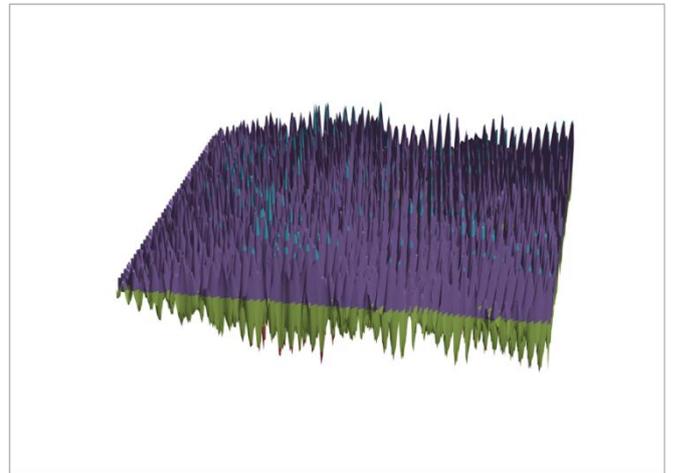


Fig. 5 (b) 11 transducers, spaced at 4 wavelengths, with 180° phase angle, 3D plot

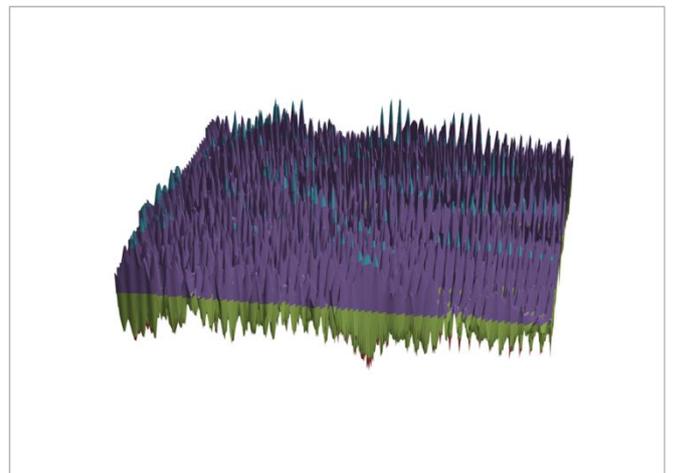


Fig. 5 (c) 11 transducers, spaced at 4 wavelengths, with random phase angle, 3D plot

There are subtle differences between the three cases shown here. For example in Figure 5(a), where the

cleaning region is defined as the right two thirds of the plot, the 0 degree phase angle results in 25% more average power per volume and a more even distribution when compared to Figures 5(b) and (c). This is a bit more evident in the 2D plots of the same data, shown in Figures 6 (a), (b) and (c). It is important to note that in these figures, the point source transducers are located at the bottom of the plot, meaning the ultrasonic plane is being projected upwards.

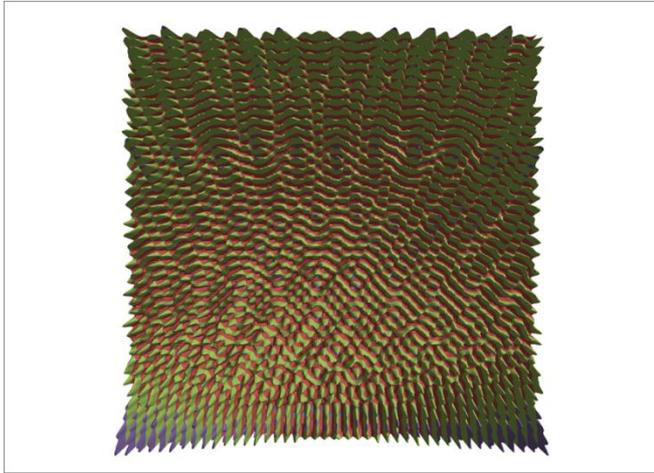


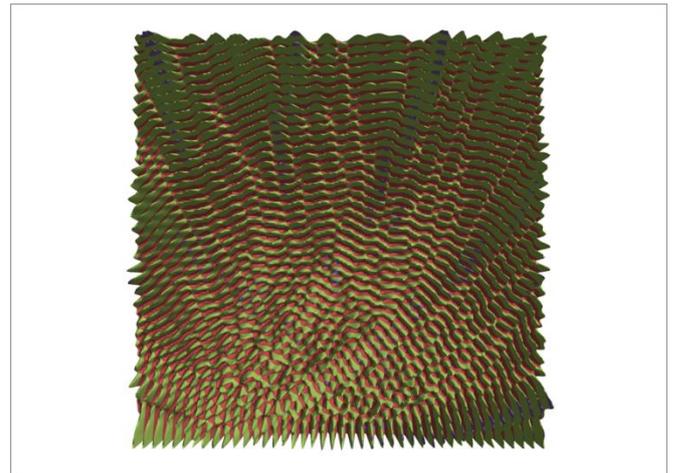
Fig. 6 (a) 11 Transducers, spaced at 4 wavelengths, with 0° phase angle, 2D plot



Fig. 6 (b) 11 transducers, spaced at 4 wavelengths, with 180° phase angle, 2D plot

Fig. 6 (c) 11 transducers, spaced at 4 wavelengths, with random phase angle, 2D plot

The model results suggest a significant nodal nature of the energy field. There are a significant amount of nodes and nodal bands (radiating bands of low and high energy). This suggests that the ultrasonic plane in front of the transducers is unevenly distributed. Furthermore, in the case of independent resonant oscillators with a random phase angle (which is the typical arrangement within our systems) there are strong nodal bands evident at significant



distances from the transducers.

The prediction of significant nodality in the fluid fits well with the field observations seen in Figure 1 and suggests that a strategy to distribute the energy more evenly would result in more efficient cleaning.

The most obvious way to compensate for the nodality is to move the parts in the field. To test the impact of this hypothesis on cleaning efficiency, a simple test was devised using bolts with an oven cured asphalt coating. The bolts were suspended on nylon line, and allowed to move up and down in a small test tank. The rotation was made possible by connecting the bolts to a motorized crank wheel turning at approximately 1 rpm. A sample of these test pieces is shown in Figure 7.



Fig. 7 Test bolts coated in asphalt and suspended by nylon line.

The test bolts were cleaned in 3 different modes: Mode 1 – the bolts were stationary in solution, Mode 2 – the bolts were moving up and down, but always submerged and Mode 3 – the bolts were positioned such that 50% of the cycle was submerged. The results of this simple experiment are shown in Figure 8. The bolts in Mode 3 (bolts 13-18 in Figure 8) which were 50% submerged were cleaned approximately 4 times faster than the stationary bolts, and approximately 2 times faster than the fully submerged but moving bolts.

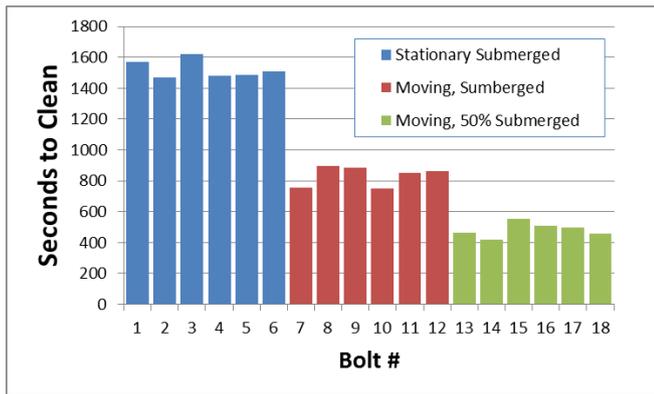


Fig. 8 Results of the moving bolts test

## RESULTS

The results of the tests using the moving bolts, combined with the observation of significant nodality in the field (suggested by the model and observed on parts in the field), have led us to propose a new heat exchanger cleaning system. This new system addresses both problems and at the same time, allows for a significant reduction in the volume of chemistry required. In order to allow the field nodes to be spread evenly along the tubes of a bundle, while taking advantage of the increased cleaning efficiency observed in the bolt test, the new system rotates the exchanger in the ultrasonic field, while allowing only partial submersion. The concept is shown in Figure 9.

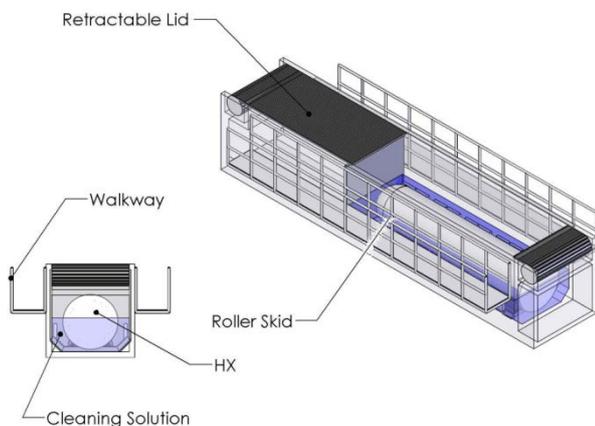


Fig. 9 New HX cleaning system concept with rolling HX, half submerged bath, flexible tank volume

Further refining of the design has led to the development of a heat exchanger lifting device with integrated rollers that are incorporated into the new cleaning system design, which is currently under construction.

## DISCUSSION AND FUTURE WORK

As a result of the experience with manual measurements, the decision to build a robotic field measurement system was made. This system is still in development as of this writing, but will provide the ability to automatically measure ultrasonic fields in 3 dimensions, over a volume of approximately 3m wide x 1 meter deep x 1.2m high. Future measurements with this new device will

help confirm the model results, and help us examine the potential for acoustic coupling between the transducers.

The model suggests that there are possible performance differences between systems of transducers with different degrees of synchronization, which will be investigated.

A new exchanger cleaning system has been designed and is being built based on this work, and our observations in the field. The new system will be field tested in 2014.

Further work is required to understand the impact of moving parts in the ultrasonic field on cleaning efficiency. We are also engaged in research to understand how modification of the transducer placement and signals may be used advantageously to provide a more homogenous energy field.

## References

- R. Phillion, S. Smith, B. Kieser, and T. McCartney. *Ultrasonic cleaning of heat exchangers: badly fouled compabloc exchangers*. Heat Exchanger Fouling and Cleaning Proceedings, 2011.
- Pan M., Bulatov I., Smith R., *Retrofit Procedure for Intensifying Heat Transfer in Heat Exchanger Networks Prone to Fouling Deposition*. Chemical Engineering Transactions. 2012; Volume 29, Pages 1423-1428
- Cho Y.I., Liu R., McFarland W.J., Fusegni L., *Study of Scale-Removal Methods in a Double-Pipe Heat Exchanger*, Heat Transfer Engineering. 2000. Volume 21, Pages 50-57
- Legaya M., Alliberta Y., Gondrexona N., Boldoc P., Le Person S., *Experimental investigations of fouling reduction in an ultrasonically-assisted heat exchanger*, Experimental Thermal and Fluid Science, Volume 46, April 2013, Pages 111-119
- Legaya M., Le Person S., Gondrexona N., Boldoc P., Bontemps A., *Performances of two heat exchangers assisted by ultrasound*, Applied Thermal Engineering, Volume 37, May 2012, Pages 60-66
- Naude C.F., Ellis A.T., *On the mechanism of cavitation damage by non-hemispherical cavities in contact with a solid boundary ASME. J. Basic Eng.*, 1961, Volume 83, Pages 648-656
- Shima A., Takyama K., Tomita Y., Miura N., *An experimental study on effects of a solid wall on the motion of bubbles and shock waves in bubble collapse*. Acoustica. 1981, Volume 48, Pages 293-301
- Kieser B., Phillion R., Smith S., McCartney T., *The application of industrial scale ultrasonic cleaning to heat exchangers*, Heat Exchanger Fouling and Cleaning Proceedings, 2011
- Herbert E., Caupin F. *Cavitation in water: a review*. C. R. Physique, 2006, Volume 7, Pages 1000-1017
- Witte R. S., Hall T., Olafsson R., Huang S., O'Donnell M. *Inexpensive acoustoelectric hydrophone for mapping high intensity ultrasonic fields*, J. Applied Phys. 2008 Volume 104(5), Page 054701