THE APPLICATION OF INDUSTRIAL SCALE ULTRASONIC CLEANING TO HEAT EXCHANGERS

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ABSTRACT

The cleaning of fouled heat exchangers often presents a significant challenge to the maintenance and operation of chemical, petroleum and food processes. Despite efforts in the design of processes and hardware to minimize fouling, eventually the intricate interior surfaces of the exchanger require cleaning to restore the unit to required efficiencies. In situ chemical rinse methods require detailed understanding of the foulant properties, and may provide incomplete removal, particularly on the shell side (o.d.) because of the complexity of the flow path. High pressure water blasting is very often ineffective at restoring a unit to 100% efficiency, can take considerable time and manpower, uses environmentally unfriendly amounts of water, and has proven to be a dangerous activity in routine practice.

Ultrasonic cleaning has been used industrially for decades, particularly to clean small intricate parts, and to accelerate surface treatment processes. This paper will describe in detail the ultrasonic cleaning process and our experience in developing very large scale equipment and processes capable of rapidly cleaning heat exchangers up to 9.5 m in length and 2m in diameter. In a year of operation, we have encountered heat exchangers fouled with a wide variety of materials from both refinery and chemical clients. Many of the exchangers we were presented with during trials have never been successfully cleaned by any other method. The results of our experiments demonstrate that a combination of ultrasound, with the appropriate chemistry and handling, provides a rapid, safe and environmentally friendly alternative to traditional methods.

INTRODUCTION

The extraction and refining of heavy crude from the bituminous sands (“oil sands”) in Canada presents many technical challenges, including the maintenance and cleaning of equipment and refinery components, which can rapidly become fouled with bitumen or related aggregates.

For over 10 years, Tech Sonic Services has been using ultrasonic cleaning baths to address the problem of badly fouled filters, valves, pipe spools and scaffolding in the oil sand mining operations surrounding Fort McMurray Alberta. The ruinous fouling of scaffolding is a problem fairly unique to the area, due to the ubiquity of bituminous sands in the mining operation, which quickly fouls maintenance equipment to the point that it was unusable and more significantly – not cleanable by any economically viable means.

Early in 2009, it was proposed that the same technology could be used to address the problem of bitumen fouled heat exchangers. Tech Sonic Services began trials on a small scale to determine the effectiveness of ultrasound combined with aqueous degreasers as a means to address fouled heat exchangers in the summer of 2009.

THE MECHANISM OF ULTRASONIC CLEANING

The surface mechanisms of ultrasonic cleaning are well understood, with many works dedicated to this science since the first commercial ultrasonic cleaning equipment appeared in the 1950’s (Cheeke, 2002). The mechanism of ultrasonic cleaning can be understood as a combination of two effects, both a result of the collapse of cavitation bubbles near the surface of an object through the formation of a corresponding shock wave and re-entrant microjet. With sufficient acoustic pressure, during the rarefaction of a sound wave, the rapid decrease in pressure results in the formation of a void bubble, or tear, in the liquid which rapidly grows, and collapses violently during a subsequent compression wave. The formation of the re-entrant microjet during the collapse of cavitation bubbles was first observed by Naude and Ellis (1961) who noted that the microjet is normally directed towards the adjacent surface. In addition

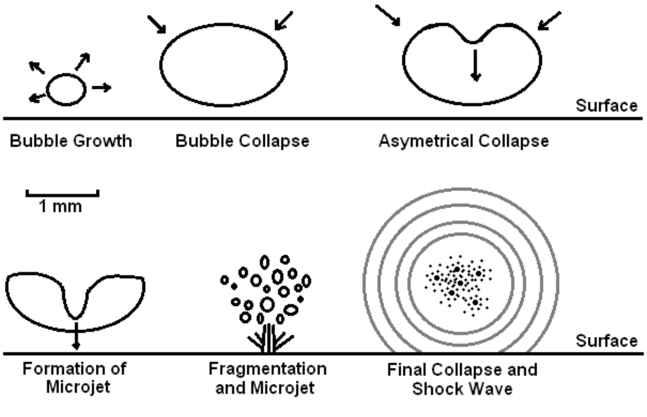

Fig. 1 The formation and collapse of a typical cavitation bubble showing the microjet and resultant shock wave, total time $< 40\ \mu s$ at 25kHz.

to the microjet, the collapse of the bubble creates a shock wave which has been observed to exhibit impinging pressures greater than those of the microjet (Shima, Takayama, Tomita, and Ohsawa , 1983). Finally, the rapid collapse of the cavitation bubbles produces extreme transient (<2μs) pressure (10^2 MPa) and temperatures (3500-8000K) inside the bubble during collapse, which contribute to the velocity of the microjet and heating of the liquid (Fujikawa and Akamatsu 1980). Figure 1 depicts the growth and collapse of a cavitation bubble.

The first cleaning effect is kinetic, resulting from improved mass transport characteristics by disturbance of the diffusion layer near the surface of the foulant. The second effect is physical, resulting from the physical disturbance of the foulant itself by the microjets. The extent to which these two effects contribute to the effectiveness of a cleaning process depend strongly on the relationship between the cleaning fluid and the foulant being removed from the object. Other described “sono-chemical” effects, such as the formation of radicals and activation of passive surfaces are less important in cleaning applications than they are in chemical synthesis, for example.

In the case of a foulant which is to be dissolved in a cleaning solvent, the effect of increased mass transfer near the surface can have a dramatic effect on the dissolution reaction rate by disruption and effective decrease of the diffusion layer near the surface. In the presence of cavitation, the diffusion layer is effectively reduced in thickness, resulting in improved mass transfer of solute into the bulk solution, far and above the effects of bulk phenomena such as agitation and convection within the fluid. This effect is well understood and reported, and our own laboratory tests demonstrate that for simple dissolutions the ultrasonic energy may increase the reaction rate by several orders of magnitude.

In the case of a foulant which is to be removed by suspension in the cleaning fluid, the mechanical disruption of the foulant by imploding cavitation bubbles (from the resultant shock waves and microjets) is likely the dominant mechanism, providing a microscopic “scrubbing” action which displaces material from the surface into the bulk solution. Macroscopic processes such as convection will distribute the suspended material throughout the cleaning fluid, enhanced by agglomeration which further separates the material away from the work piece.

METHOD

Heat exchangers are typically (historically) cleaned on-site by removing the exchanger and placing the unit on a wash pad for spraying with high pressure water to remove foulants. In some cases, more automated spraying equipment and mechanical/high pressure lancing equipment may be used to open and clean blocked tubes.

The method of cleaning heat exchangers in an ultrasonic bath requires specially designed vessels, capable not only of holding sufficient fluid to effect the cleaning, but the bundle itself in a useful orientation, and designed to allow easy removal of the foulant material from the immersed bundle.

Based on our experience to date, the typical bundle cleaning process takes from 4 - 8 hours, depending on the specific condition of the bundle. The process variably involves repositioning of the bundle to ensure that all tubes are liquid filled, intermediate rinsing at low pressure to remove loosened material, and monitoring of the cleaning fluid to ensure continued activity. For scale removal operations, the process is typically simpler, as the scale removal alone does not require as much intervention, since the process is a combination of dissolution and suspension.

In order to test the approach, in the summer of 2009 a small (4m x 1m) 250 U-tube heat exchanger was diverted from the normal cleaning regimen during a refinery turnaround and treated with the ultrasonic-based technique in combination with a small amount of low pressure water rinsing. The ultrasonic bath used was already being used to clean process parts and scaffolding at a Tech Sonic Services facility. The heat exchanger was fouled on the shell side with bituminous hydrocarbons and on the tube side with (mainly) calcium carbonate scale.

The second trial of the approach was conducted on a much larger heat exchanger. In order to accommodate a larger unit, and maintain sufficient ultrasonic cleaning power throughout the active volume in the vessel, a new design of vessel was created. A vessel 9m x 2.75m (liquid capacity 28,000 litres) was constructed, which was capable of delivering in excess of 5 Watts/litre of energy in the volume to be occupied by the work piece. Total power dissipation of the unit was >140,000 Watts. The arrangement of transducers was specifically engineered to direct the ultrasonic energy such that sufficient energy was available to the interior spaces of the large bundle. The vessel was further designed to allow gravity to assist in removing loose foulant from the tubes. The bundle was treated for several hours in a proprietary aqueous degreaser with a small amount of solvent added to enhance the fluid effectiveness with the anticipated foulant. Handling and rinsing procedures were optimized to improve the efficiency of the cleaning process.

The bundle chosen for the second test was a unit that had been removed 3 years previous to cleaning and was sitting in the scrap yard. Previous attempts to clean the bundle using high pressure water had failed, and the customer was thus unable to dispose of the fouled bundle. A large fraction of the tubes were blocked with solidified bitumen, and the exterior of the tubes were fouled with a mixture of hydrocarbons, sand and rust from exposure.

In both tests, the cleaning solution was used for subsequent cleaning activities, and once the effectiveness of the fluid was diminished (determined by monitoring several chemical properties of the fluid), the entire vessel was emptied and the solution disposed of.

RESULTS

The first smaller unit was treated for 4 hours in the ultrasonic vessel with a proprietary aqueous degreaser with periodic rinsing to check progress. The heat exchanger was readily cleaned on both the inside of the tubes (i.d.) and the outside of the tubes (shell side – o.d.) to bare metal and returned to service condition in less than 1 day. Based on weight measurements, approximately 150 kg of material was removed from the bundle.

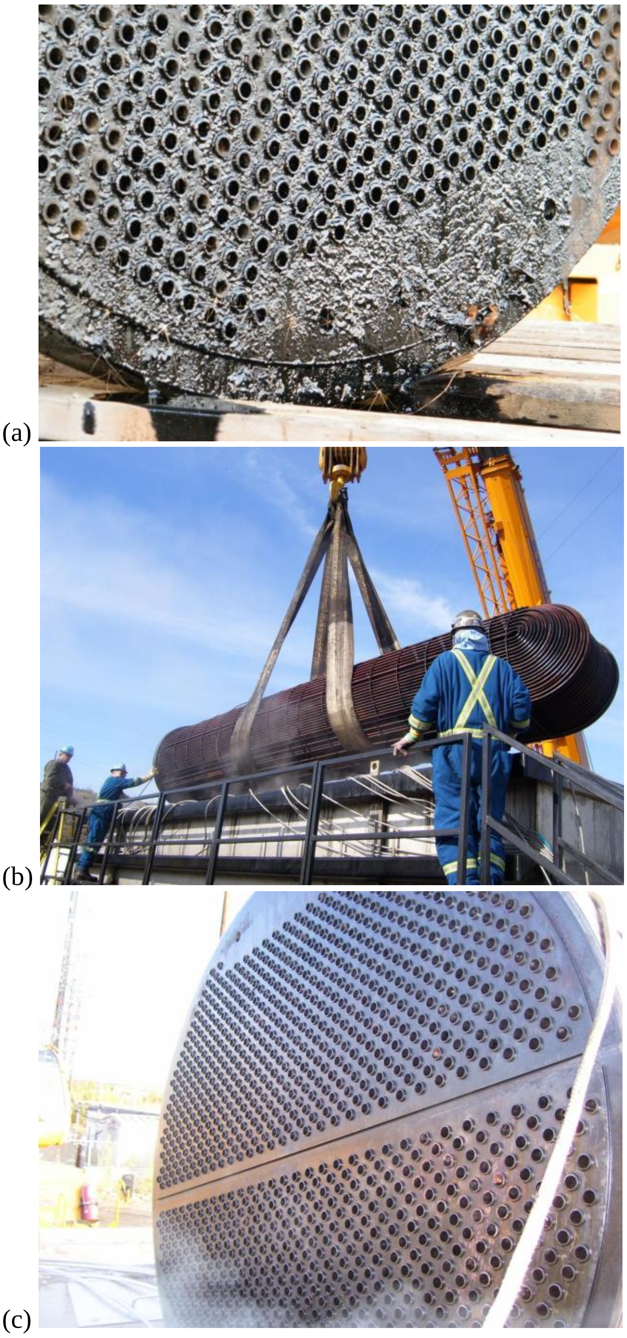

Fig. 2. (a) Large test bundle tube sheet before cleaning. (b) bundle being inspected during the cleaning process. (c) Test bundle after cleaning process.

The second larger bundle, tested in the large vessel had similar results. The bundle was treated for several hours in a proprietary aqueous degreaser with a small amount of solvent, at which point the loosened material began to flow freely from the tubes. Several rinse and re-immersion procedures performed over six hours were sufficient to clean both the ID and OD of this scrap bundle to bare metal, in effect restoring the scrap bundle to fully operational condition. In total, over 1000 kg of foulant was removed from this bundle. Figure 2(a) shows the fouled bundle tube sheet, 2(b) shows the bundle being raised for immersion and Figure 2(c) shows the cleaned bundle.

IRIS testing has been used on several subsequent test bundles to confirm complete removal of the foulant from the insides of tubes.

DISCUSSION

Testing of the new large vessel continued in the fall of 2009, with the same success repeated on a variety of bundles in the Fort McMurray Alberta oil sands mining and refining operations.

The success with the large vessel spurred further development of the vessels to provide larger capacities, with active volumes of 10.5m x 2m x 2m. In the subsequent year, using a number of large vessels, we have successfully cleaned hundreds of heat exchangers in the petroleum and petrochemical industries. The more recent work exposes the most significant limitation of the technique; specifically that it may still be necessary to use traditional methods to unblock tubes to permit filling with liquid without which there is no ultrasonic cleaning. Also, in situations where acidic or basic cleaning solutions must be used, careful testing and evaluation is required to avoid deleterious effects on metal parts.

CONCLUSIONS

The test results have demonstrated that a combination of very large, specially designed ultrasonic vessels with tailored chemistries and optimized handling techniques provides an effective means of cleaning heavily fouled heat exchangers. Advantages demonstrated include:

1. Significantly faster turnaround (typ. <8 hours)
2. No deleterious effects on the bundle materials
3. Far less waste water generated (typ. <2000l per bundle) when contrasted with high pressure water blasting
4. The technique is safer than high pressure water blasting, presenting no significant hazards to the operators
5. The technique has been 100% successful at cleaning both the inside and outside of heat exchangers
6. The action of the ultrasonics is able to access the interior of the tubes, and the interstitial spaces of the tube bundle

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