

Ultrasonic Chemical Cleaning: Development of Chemical Blends for Industrial Applications

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ABSTRACT

Ultrasonic cleaning is a technique which originated back in the 1950s and has seen widespread use in medical and scientific laboratories, but the application of ultrasonic cleaning to industrial process equipment remains a relatively new technique which is still gaining headway in the North American markets. The challenges of upscaling the process of ultrasonic cleaning continues to push the development in this field to new innovative applications and advancement in the understanding of surface responsive techniques.

The development of chemical blends for ultrasonic chemical cleaning applications is a science unto its own. Ultrasonic cavitation provides an activation energy which disrupts the bonding of scale deposits with the surface of industrial equipment. The intensity of the cavitation relies on the formation and collapse of bubbles at the substrate surface. The surface tension of the chemical must be considered in order to provide an effective cavitation media, as does the dynamic contact angles of the chemical blend with the substrate to ensure effective wetting of the deposit. Furthermore, the chemistry itself must be compatible with the deposit to gain the synergistic influence of combining the chemical and mechanical techniques.

A discussion on the development of ultrasonic chemical cleaning blends is presented. A consideration on the requirement for oxidative corrosion control is also conferred. Finally, an examination of variances observed in the progression from laboratory testing to field studies is considered to complete this review.

Key words: Ultrasonic Cleaning, Chemical Cleaning, Cavitation, Surface Responsive, Surface Tension, Contact Angles, Oxidative Corrosion, Chemical Blending, Mechanical Cleaning, Field Application

INTRODUCTION

The cleaning of equipment using ultrasound is a technique which has been utilized effectively in industrial settings for decades. More recent advances have looked towards the cleaning of larger and larger pieces with varied success. As the technology develops, so too does the chemistry, and the applications towards which this type of process can be directed.

The introduction of large scale immersion based tanks for the express purpose of cleaning fouled heat exchangers was introduced in 2009 by Kieser et al. (2011) [1]. Traditional cleaning of heat exchangers in industrial processes such as petroleum, agriculture, food and chemical processes often presents substantial challenges, particularly where intricate interior or interstitial surfaces are involved. These areas are often difficult to access by *in situ* chemical wash due to complex flow patterns which can be further influenced by fouling build up. Application of High Pressure Water Blasting (HPWB) on the Outer Diameter (OD) of heat exchanger bundles can take considerable time and manpower and is rarely effective in restoring the unit to 100% efficiency. Furthermore, HPWB is not only a dangerous activity in routine practices but it is also an environmentally unconscious practice, as it utilizes extensive amounts of water which now comes with hefty consumption fines in certain markets, such as in the European Union, and in states such as California and Texas.

Ultrasonic chemical cleaning combines both the mechanical influences of ultrasonic technology and the chemical activity of chemical cleaning to optimize and accelerate the surface treatment of industrial equipment, returning parts to service at higher efficiencies and in less time than traditional cleaning methods in the majority of cases. The focus of this paper will be directed towards the development of the chemistries for this type of application, but it would be remiss to not include an explanation of the mechanism of action of the Ultrasonic method herein.

Mechanism of Ultrasonic Cleaning

Ultrasound waves are produced at frequencies above the limits of human audibility. The sound wave displaces the media in an oscillatory fashion, resulting in compression (positive pressure) and subsequent rarefaction (negative pressure) within the media, this concept is shown in figure 1. The decontamination of surfaces by acoustical waves produced at ultrasonic frequencies is particularly effective because of two contributing factors related to the cavitation of the liquid medium.

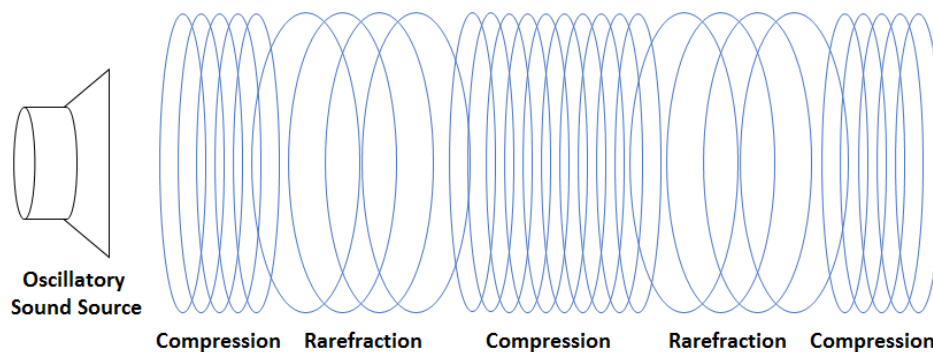


Figure 1: Compression and Rarefaction of Oscillatory Sound Waves

First, at acoustical pressures above the cavitation threshold, the sound wave travels through the medium until it contacts a surface, at which point the rarefaction of the sound wave results in a rapid decrease of pressure in the liquid medium and the formation of a void “bubble” or tear which grows rapidly until its collapse. The collapse of the bubble is asymmetrically directed towards the adjacent surface and results

in the formation of a powerful jet normal to the surface which can serve to dislodge hard scales and sticky deposits. This concept is depicted in figure 2.

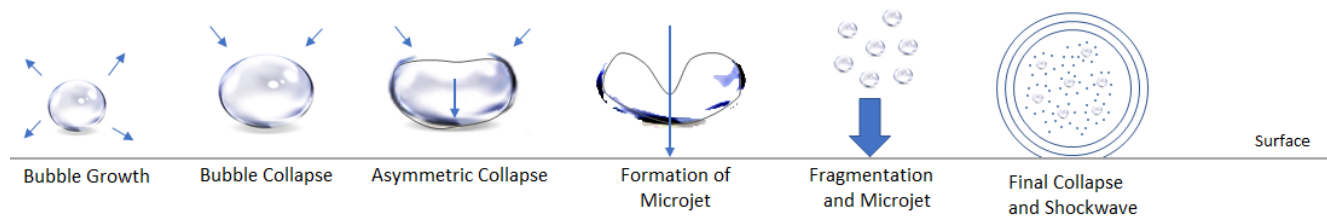


Figure 2: Growth and Collapse profile of a typical cavitation bubble in solution showing the formation of a microjet normal to the surface and subsequent shockwave.

Secondly, the thermodynamic properties of the growth and subsequent collapse of the cavitation bubble are incredibly powerful. The growth phase of the cavitation bubble creates a rapid decrease in local temperature as the void is created [2]; however, as the bubble collapses in on itself the sudden increase in local temperature is remarkable, on the order of 3500-8000K [3]. Bubble collapse also results in a transient pressure change on the order of 10^2 MPa (10^5 psi), which contributes dynamically to the velocity of the produced microjet, with ultrasonic streaming velocities of 400 km/h (250 mph) observed [4].

Furthermore, as the acoustic waves pass through a liquid medium, fluid streaming occurs which serves to reduce the hydrodynamic boundary layer breaking the adhesive forces between particles and surface, reducing redeposition [5]. Thus, the effects produced by the ultrasonic waves in solution are important on both the microscopic and macroscopic scale.

Chemical Considerations

The fluid medium plays an important role in the effectiveness of the clean, as it is required not only to transmit the ultrasonic waves from the transducer to the equipment surface [6], but also serves to solvate the foulant. Thus, the characteristics of the chemical blend must be considered carefully.

Chemical Characteristics to Consider

1. Effectiveness on the deposit
2. Compatibility with the metallurgy/coatings
 - a. Of the equipment to be cleaned
 - b. Of the Ultrasonic Tank and Transducers
3. Temperature
4. Viscosity
5. Surface Tension
 - a. Liquid to air/void
 - b. Liquid to scale
 - c. Liquid to equipment surface
6. Vapour Pressure
7. Robustness
8. Chemical Loading/Spending
9. Oxidative Corrosion Control

Effectiveness on the Deposit

Of any of the considerations listed here, the effectiveness of the chemistry towards the scale is of utmost importance. The ability of the chemical blend to solvate the scale under Ultrasonic conditions must be tested. It is important to obtain representative samples of the fouling deposit to be removed whenever possible. Chemical blends which have been developed for Ultrasonic Chemical Cleaning applications by the lead authors include a range of aqueous degreasing blends, solvent-based microemulsified

degreasers, acidic and caustic chemistries, stabilized oxidizers and specialized dispersants. Each of these chemical blends have been designed with a particular subset of foulants in mind, and have been tested against a wide range of fouling materials for their effectiveness.

Compatibility with the Metallurgy/Coatings

Of course, when cleaning any type of equipment, consideration with regards to the metallurgy of the equipment to be cleaned must be given. Whenever possible, representative coupons of the metallurgy are tested in the chemical blend under Ultrasonic Chemical Cleaning conditions to determine what, if any, corrosion rates may be present, and whether corrosion may be inhibited by the addition or substitution of a specific chemical component.

Equipment may have corrosion resistant coatings present that must also be taken into consideration. A customer may request that the coating be removed, or alternatively be kept intact during the chemical cleaning. This may also be the case for gaskets and seals.

The metallurgy of the ultrasonic immersion tank must also be considered in order to prevent premature failure of the Ultrasonic transducers and corrosion to the tank walls.

Temperature

As with any chemical cleaning solution, the temperature at which it is applied is an important factor to consider. The temperature of the solution not only has an affect on the kinetic rate of dissolution or dispersion of the fouling, but also the viscosity of the fluid, the diffusion rate of dissolved gases in solution, and the vapor pressure. The importance of each of these factors is discussed further.

Another point that must be considered is that of cloud point. For aqueous surfactant blends, the cloud point is the temperature at which the mixture begins to phase-separate. Above the cloud point temperature, the cavitation of the fluid will be affected, as a single phase solution is no longer present, and the surface tension of the solution is no longer stable.

Viscosity

Transmission of acoustic energy is a function of the viscosity. From Stokes' law (see equation 1), the attenuation of the acoustic wave decreases exponentially as a function of the both the viscosity and the density of the liquid (see equation 2), so small changes in viscosity result in large changes in the efficiency of acoustic transmission. Thus, minimizing the viscosity of the fluid medium is essential to maximizing acoustic cavitation.

$$A(d) = A_0 e^{-\alpha d} \quad (1)$$

Where α is the dimensionality of the reciprocal length for the Amplitude. A_0 is the amplitude of the sinusoidal pressure wave, $A(d)$ is the Amplitude after traveling some distance, d .

$$\alpha = \frac{2\eta\omega^2}{3\rho V^3} \quad (2)$$

Where η is the viscosity of the medium, ω is the angular frequency of the sound wave, ρ is the density of the medium, and V is the speed of sound in the medium.

In highly viscous liquids, the acoustic waves may be propagated not only via the normal longitudinal elastic waves, but there may also be propagation along the transverse (shear) waves, which can produce anomalous absorption and dispersion of the acoustic energy [7]. Thus, the more viscous a liquid is the more lethargic it will be in response to the rarefaction, and the growth of the cavitation bubble may be stalled as a result. It is for this reason that an aqueous chemical base is most often employed in generating the ultrasonic chemical cleaning blends.

Furthermore, as the cleaning process progresses, it is important to monitor any changes to the viscosity of the fluid medium. This serves as an indicator of chemical loading. The application of emulsion and micro-emulsion based cleaning chemistries means that hydrocarbon fouling can often be carried in the