

# PHYSICO-CHEMICAL PROCESSES OF CONVENTIONAL SOIL RELEASE VIS-À-VIS ULTRASONIC CLEANING OF TEXTILES

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## ABSTRACT

*Manufacture and marketing of household washing machines and detergents is a multibillion dollar industry worldwide (www.strategy.com). That is why substantial investment in R&D has been undertaken by manufacturers to maintain or improve their competitive position. The research in last six decades has focused on gaining a fundamental understanding of soiling and detergency mechanism. As a consequence there are numerous publications as well as text books which deal comprehensively with theory and technology of detergency. However use of High frequency Ultrasonic waves as a means of cleaning textiles is a new domain which is being explored and researched as an alternative for laundry process intensification. This paper presents in detail the physico-chemical processes of soil release that are taking place in the conventional washing. The paper is also intended to advance the understanding of Ultrasonic principles as delineated in acoustics, to get a comprehensive insight into ultrasonic cleaning process. The discussion is undertaken for the purpose of integrating the concept of ultrasonic energy as a substitute for agitation (mechanical energy) in the aqueous cleaning process and outlines the direction for further research.*

**Key words:** Conventional Soil Release.

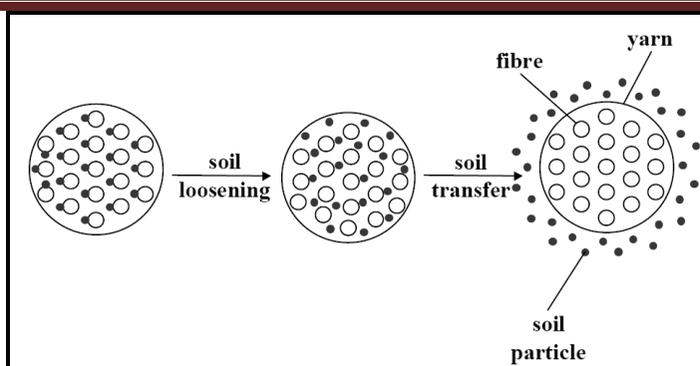
## 1. INTRODUCTION

The efficiency of a given laundering process in effecting soil release from textiles is a complex function of the nature of the soil, the manner in which the soil was originally distributed in the fabric, the surface energy of the textile fibers, the fiber surface topography, and the overall fabric construction.

Four factors in proper combination are necessary in any cleaning process namely time, temperature, agitation and chemistry of the detergent. Two main methods of cleaning textiles are aqueous cleaning and dry cleaning. **Aqueous cleaning** is a method of removing contaminants from the textiles using water. In the **dry cleaning** process, the solvents are substituted for the water while the remaining factors of cleaning remain the same. Aqueous cleaning is environment friendly compared to chlorinated and other ozone depleting chemicals used in solvent cleaning. It offers advantages like reduced solid wastes and air emissions and is therefore witnessing a revival of interest from consumers, researchers as well as industry.

## 2. AQUEOUS CLEANING PROCESS

Chemistry of the cleaning agent, time, temperature and agitation/mechanical energy are the keys to the aqueous cleaning process. These factors have to perform a separation process in which soil is removed from a textile substrate. In that process, two important steps can be distinguished: the soil loosening step and the soil transfer step (Figure 1). In the soil loosening step, the physical binding forces between the soil and the substrate are broken up. In the subsequent soil transfer step, the loosened soil is transported from the substrate to the wash liquor (Moholkar, 2002.) A detergent is a material intended to assist in cleaning. 'Detergency' is a measure of cleaning power (Bhattacharaya, 2009). Detergency is defined as "The removal of unwanted substances, called soils from a substrate immersed in some medium, generally through the application of a mechanical force, in the presence of a chemical substance which may lower the adhesion of the soil to the substrate" (Florescu *et al.*, 2002).



**Figure 1: Transport of Loosened Particle Soil from the Yarn to Bulk due to Convection**

Detergents were developed in response to shortage of animal and vegetable fats used to make soap in World War I and II. General structure of detergent is  $R-SO_4Na^+$ . Detergent is structurally similar to soap but differs in water soluble portion ( $-SO_4Na^+$ ) instead of ( $-COO-Na^+$ ). Surface active agent present in detergent belongs to a chemical class of highly polar, high molecular weight molecules, when added to water, these molecules form a cluster called micelles, in which polar ends of the molecules are on outside of the cluster and non polar ends of the molecules are in the middle (Bhattacharya, 2009). These molecules can be anionic, cationic or nonionic in aqueous solution. The surfactant molecules congregate at the oil-water interfaces so that an oily droplet rolls up from fabric surface and is disengaged from fabric with the aid of mechanical action in laundering process (Webb and Obendorf, 1987a,b). In the washing process, a complex mixture of soils must be removed, consisting of compounds physically adsorbed and/or covalently bound on textile substrate. The removal efficiency of surfactants depends on nature of surfactant and correlates with their adsorption on textile substrate (Fort *et al.*, 1966b). Modern detergents include various components besides the surfactant called auxiliaries and are incorporated in small amounts to boost performance. These are builders, bleaches, enzymes, optical brightening agents, soil anti-redeposition agents, foam regulators, corrosion inhibitors, perfumes, color and fillers. These components have synergistic effects on one another and boost the overall cleaning performance. Detergents remove soil by sequestration, dissolution, wetting, emulsification, deflocculation, dispersion and/or saponification.

*Sequestration* – sequestering agents are generally powders or liquids which combine with calcium, magnesium and other heavy metals in hard water. They form molecules in which these ions are held securely or sequestered, so that they cannot form insoluble soaps with fatty acids

*Dissolution*- is a process whereby water soluble salts are dissolved in the alkaline solution and then flushed away in the rinse.

*Wetting* – surfactants enable wetting by lowering surface tension and interfacial tension so that the cleaning solution can penetrate even the small spaces and get under the soil and lift it from the substrate. Water is not attracted to oily surface (hydrophobic), but with surfactant, wetting occurs as molecules from its hydrophilic group absorb at the oil-water interface making it spreadable on to the substrate surface. Small oil droplets become negatively charged, repel each other and remain suspended in washing water, which during rinsing is flushed away.

*Emulsification*- is the primary means of removing oils when using alkaline or aqueous cleaning. The oils are broken up into tiny droplets that are suspended in a solution and are flushed away in the rinse.

*Deflocculation/ Dispersion/ Solubilization* – is used in removing solid oils that have aggregated. It works by breaking the attractive forces holding the particles together, thus breaking up the solids into small fine particles that are dispersed throughout the cleaning media. The soil/liquid matrix is maintained as a dispersion or colloidal suspension, preventing agglomeration.

*Saponification* – alkaline hydrolysis or breaking up of insoluble fats into water soluble soaps and glycerin, which help in emulsification. This is used for solvent free defluxing and degreasing (Lomax, 1996; Smulders, 2000).

### 3. PHYSICO-CHEMICAL ASPECTS OF SOILING AND SOIL RELEASE

Soiling and soil release are complex phenomena involving the interrelationships of the nature of the fiber surface, fiber-fabric structure, nature of soil, chemical finish and detergent.

#### 3.1 Nature of Soil

Soil on a textile fabric comes from two sources, body of the wearer and from the environment. Analytical studies have shown that the soil deposited on apparel and furnishing is a mixture of a fluid component usually oil or grease and a solid component made up of small particles, the composition of which varies according to the source (Venkatesh *et al.*, 1974). Lubricating oils and greases from automobiles and machinery, secretions from the human skin, oils and fats from food and cosmetics are a common source for the fluid component. A substantial part of soil present on domestic laundry is sebum secreted by sebaceous glands in the skin and is found at levels of 0.5-1% on clothing worn next to skin and bed linen. Sebum contains some hydrocarbon such as squalene but primarily it has triglycerides and fatty acids (Bishop, 1995). The major particulate constituents of soil are clay minerals of varying particle size (Kissa, 1973). Another source of soil is the wash liquor itself, soil redeposition or wet soiling, takes place during laundering due to pick up by the fabric of soil suspended in the wash liquor (Fort *et al.*, 1966a).

Many analytical studies have been undertaken to identify the constituents of natural soil present on dirty laundry so that it can be replicated for detergency studies. Analyses of natural soils have shown that both fatty and inorganic constituents are present, the exact proportions of which depend on the source of the dirt (Fort *et al.*, 1966a). Brown (1947) determined the composition of the oily constituent of dirt from a number of domestically soiled cotton fabrics, with the following results: Free long chain fatty acids (31.4%), Long chain neutral fat (triglycerides 29.2%), Short chain fatty materials (3.3%), Acetylatable material (fatty alcohols, cholesterol, etc. 15.3%) and hydrocarbons (21%). The fatty and the inorganic constituents present in the irremovable residue left on soiled cotton fabrics after laundering were analyzed and it was found that the average composition of the oily constituents was: Free Fatty Acids (3%), Esterified Fatty Acids (50%), Lime Soaps (23%) and Unsaponifiables (24%). The major particulate constituents were clay minerals 0.2-1.00 microns in diameter.

#### 3.2 Mechanism of Soiling

Fabric is soiled either by direct contact with another soiled surface or by contact with air-borne or liquid-borne substances. During direct contact mechanical forces transfer oily and particulate soil directly from a soiled surface to the fabric surface. Soil particles floating in the atmosphere settle down on the fabric surface because of gravity or are intercepted by the fabric and the finer particles may even diffuse into the fabric structure. Liquids coming in contact with fabric evaporate leaving behind dissolved or suspended particles (Venkatesh *et al.*, 1974). Also, small particles adhere to any surface with which they come into contact because of Vander Waal forces. The contact area between soil and fiber, which depends on the force of impact, affects both the amount of soil deposited on fibers during soiling and the amount of soil remaining on the washed fabric (Kissa, 1979). In the case of hydrophobic fibers, a large surface charge density is built up on the fiber surface by friction during use or laundering and soil particles, whether charged or not, are attracted from the atmosphere or the wash liquor (Venkatesh *et al.*, 1974). Soil is retained in the fabric by mechanical and electrostatic forces or by oil bonding. The fluid component picks up and retains particulate soil which is termed as oil bonding (Snell *et al.*, 1950). Mechanical entrapment or occlusion of particles also takes place (1) In the inter-fiber and inter yarn spaces (macro-occlusion); (2) in the irregularities of the fiber surface (this is the mechanism responsible for entrapment of fine soil particles in surface textured fabrics like cotton, silk, wool and textured synthetic fibers); and (3) within the crevices and pores (micro-occlusion) (Compton and Hart,

1953a,b; 1954). In the case of oily soils, capillary forces influence the advance of the fluid into the yarn. The capillary pressure  $p$  is given by

$$p = \frac{2\nu \cos\theta}{r}$$

Where  $\nu$  is the surface tension of the fluid on the fabric surface and  $r$  is a parameter characterizing the air column separating the fibers in a yarn, and hence depends on yarn construction. Therefore in a dry state the fluid will generally be held by the strongest forces in the surface irregularities of single fibers and at the fiber junctions or cross-over points, because in these areas a given volume of fluid will present the least interfacial area with air and the capillary forces will have maximum effect (Smith and Sherman, 1969). This was later confirmed by Webb and Obendorf (1987b) while studying the distribution of natural soils and they reported oily soil on the surfaces of polyester and cotton fibers and in the interfiber spaces of the yarn bundle. Oil was also found in the crenulation, secondary walls, and lumen of cotton fibers. Presence of waxes creates hydrophobic surfaces, which contribute to increased oil retention at fiber surface and lumen (Obendorf *et al.*, 1982). Oil was located in the interior of some worn (cracked) polyester fibers, but no oil appeared in polyester fibers that were not damaged. Composite (oily plus particulate) soil was detected in the same location on many fiber surfaces. It was also seen that nonpolar soils had greater affinity for hydrophobic fibers like polyester (Moris and Prato, 1982). The nature, particle size, and distribution of soil, fabric construction (both yarn and fabric structure), fiber morphology, and its chemical nature have great influence on the soils' retentive characteristics (Smith and Sherman, 1969).

Different experimental techniques which give useful information about the physical, chemical and mechanical aspect of soiling and soil release have been attempted and reported by several authors. These are:

*Microscopic Techniques* - Optical and electron microscopic techniques have been employed to study the nature, location and distribution of soil retained on the fabric surface as well as the manner and efficiency of soil removal under various conditions of soiling and laundering and also to assess the influence of fabric and yarn construction, fiber morphology, and surface characteristics in promoting entrapment and retention of soil (Fort *et al.*, 1966a).

*Surface Energy* - The surface energy of the fiber-soil interface is an important parameter but it cannot be measured directly on the fabric. Contact angles of a number of liquids of different surface tensions on the fabric surface under investigation are determined. A plot of the cosine of the contact angle against the surface tension of the liquid is a straight line which when extrapolated to cosine 1 ( $\theta = 0^\circ$ ), gives the critical surface energy of the surface. Since the fabric surface is not flat, the wettability of the surface is influenced by the fabric geometry (yarn and fabric structure) and the capillarity of the fabric in addition to the surface energy. Hence the contact angle of the liquid of the lowest surface energy that does not wet the surface and the contact angle of the liquid of the highest surface energy that does wet the surface gives the critical surface energy of the fabric surface. The values of the oil-air interfacial energy of the fluids obtained in air are useful as a guide to the resistance of the fabric to fluid soiling; and the values of the critical surface tension for wetting in water, as a guide to the phenomenon of wet soiling and ease of soil removal.

*Work of Adhesion* - Useful information can be obtained by determining the work of adhesion  $W$  using some suitable oil as reference material.

$$W = \nu (1 + \cos\theta)$$

where  $\nu$  is the surface tension of the oil in air or the interfacial tension of the oil against water, and  $\theta$  is the contact angle. It is, however, necessary to use an oil with a contact angle greater than  $90^\circ$  in air, because if it is less, it will wet the fabric surface. As the soiling increases, the work of adhesion in air decreases, indicating difficulty in wetting the fabric surface with water. A decrease

in the work of adhesion of oil in water, on the other hand, indicates good detergency, since soil becomes easily removable in the detergent solution (Venkatesh *et al.*, 1974).

**Wettability Test** - In order to get good soil removal, complete wetting of the fabric is very essential for the effective interaction with the wash liquor. A simple test [IS: 5785 (Part V)-1970] can be carried out by noting the time taken by the test fabric to become wet with distilled water. Increased wettability, i.e., a decrease in the time taken to wet the fabric surface, indicates better detergency.

**Zeta Potential** - Under the conditions encountered in practice, most soil particles are charged, as a result there is an interaction between the electrical double layers of the fabric and soil particles in water and this interaction has an important effect on detergency. Since the electrical potential of soil particles is essentially constant, the relative interaction potential between fabric and soil is obtained from the zeta potential of the soiled fabric. 1g of fabric is plumed between the electrodes of the cell, the electrolyte is streamed through this plug, and the streaming potential is measured with an electrometer; the zeta potential is calculated. A decrease in the negative zeta potential indicates good detergency action (Katsumi and Tsuji, 1969). To assess the importance of the hydrophilicity of fibers, properties like: surface charge density, dielectric constant, conductivity, moisture regain, and permeability of the fabric to air and water have also been studied.

### 3.3 Mechanism of Soil Release

Several mechanisms are operable during washing. Both the loosening and the rinsing consist of a number of physical processes, which depend on the type of soil, detergents, pH, agitation, etc. (Ganguli and Eendenburg, 1980). During loosening, the soil loses all the contacts with the fiber and is free to move anywhere in the three-dimensional structure of the textile. Several mechanisms of loosening have been suggested in the literature, such as breaking of fluctuating soil fiber bonds (Schott, 1975) or rolling up of the liquid layer (Kissa, 1971).

The rinsing of the loosened soil is governed by the hydrodynamics, as it governs the diffusion of water and detergent to the soil-fiber interface (Kissa, 1975). As discussed earlier, mass transfer in the textile is a combination of convection (between larger inter-yarn pores) and diffusion (between smaller intra-yarn pores); overall mass transfer in the textiles is mainly determined by the thickness of the boundary layer between the textile and the bulk. At high Reynolds number (fast agitation of the liquid), the boundary layer vanishes, and the transport is mainly determined by convection. This effect is even more pronounced for the textiles with a higher porosity, besides this, the rigidity and the swelling characteristics of a textile in water also influence diffusion (Ganguli and Eendenburg, 1980).

Soils of practical concern are liquid oily soils, solid soils, and mixed liquid-solid soils. The detergency mechanisms for oily (liquid) soils and particulate soils are different. Only liquid soils can separate spontaneously from fibers immersed in water. Solid soils require mechanical action for their dislodgement (Kissa, 1981).

Oily-soil detergency has three consecutive steps,

(a) An induction period, during which water and detergent diffuse into the soiled substrate, but soil removal is slow or insignificant. The length of the induction period depends upon the rate of agitation, the nature of the soil, the detergency, and the substrate.

(b) During the soil-removal period, oily soil separates mainly by the roll-up mechanism other mechanisms, such as solubilization, emulsification, and soil penetration are less important.

(c) In the final period, soil removal is very slow or negligible.

The roll-up of oil is caused by interfacial tensions of oil on fiber, water on fiber, and between oil and water. Roll-up can be enhanced by increasing the interfacial tension between oil and the fiber surface and decreasing the interfacial tension between water and the fiber surface. In other words, the fiber surface has to be made more hydrophilic (Kissa, 1975). In the detergency process, an increase in soil removal generally occurs with increased wash water temperature (Morris and Prato, 1982, Obendorf *et al.*, 1983). The effect of wash water temperature on soil removal depends on the textile substrate and the nature of the soil (Breen *et al.*, 1984). The

concentration of oil markedly reduced in the crenulations of the cotton fibers and the small interfiber spaces between closely spaced polyester or cotton fibers at higher temperatures (Bubl, 1970).

Particulate soil is generally embedded in a sheath of oil spread over the fabric surface and its removal involves breaking the adhesive bond and wetting the separated soil and fiber surfaces. The particle is then transported into the wash liquor (Kissa, 1978). Earlier studies have shown that fiber topography controls micro-occlusion, while the yarn and fabric construction determine the macro-occlusion of particulate soil.

Naturally-occurring soils usually contain both particulate matter and fatty or oily soil. The detergency of such mixed soils depends on the removal of the fatty film on fibers and benefit, therefore, from a hydrophilic fiber surface (Kissa, 1981). Also polar soils are easier to remove by aqueous detergent systems than non-polar soils (Chi and Obendorf, 2001).

Thus soiling is a process of wetting or adsorption of fluid soil over the fabric surface, and soil release is a desorption process that involves the displacement of one interface and the formation of two new interfaces (oil-water and fabric-water). Any modification or treatment which increases the energy of the fabric-water interface and reduces the energy of the fabric-oil interface would adversely affect the soil release characteristics of the fiber.

#### 4. THEORY AND FUNDAMENTALS OF ULTRASONIC

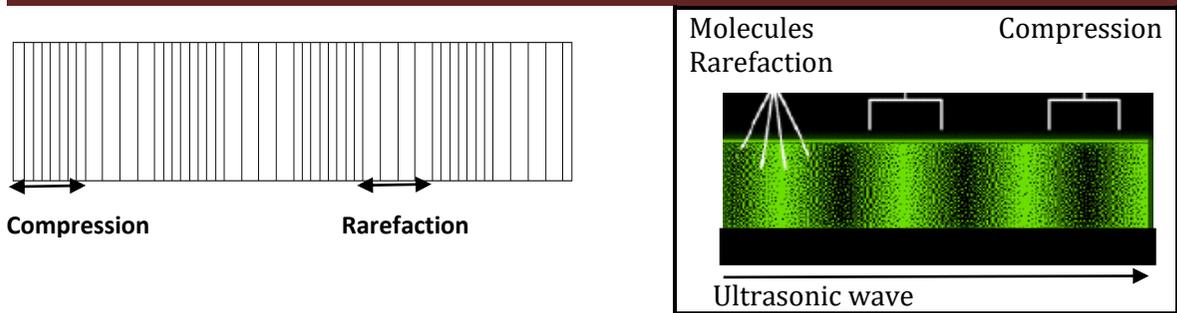
Ultrasound is high frequency sound wave inaudible to humans ranging from 18 kHz-10MHz. In practice, three ranges of frequencies are reported for distinct uses: low frequency or power ultrasound (20-100 kHz), medium frequency (300-1000 kHz) and high frequency or diagnostic ultrasound (2-10 MHz) (Ince *et al.*, 2001). Ultrasonic vibrations travel in the form of a wave similar to the way light travels but unlike light waves which can travel in vacuum, ultrasound requires an elastic medium such as a liquid or solid with elastic properties for propagation.

Ultrasound produces its physical and chemical effects through several different mechanisms but the most important is the phenomenon of cavitation. **Cavitation** is the formation, growth and collapse of gas or vapor filled micro bubbles or cavities under the influence of pressure variation in medium. Different kinds of cavitations based on the cause of pressure variation are:

1. **Hydrodynamic Cavitation** is caused by the pressure variation in the flow of a liquid, due to variation in the velocity of flow.
2. **Acoustic Cavitation** is due to pressure variation in the liquid caused by passage of an acoustic wave.
3. **Optic Cavitation** is due to high-intensity light such as laser which results in rupture of liquid.
4. **Particle Cavitation** is produced by any type of elementary particle (for example proton) rupturing the liquid as in a bubble chamber.

Of these only the hydrodynamic and acoustic (or ultrasonic) cavitation have potential towards large-scale application, due to the simplicity of the method of creating them while others are basically useful for fundamental research in cavitation due to high cost of operation (Moholkar, 2002).

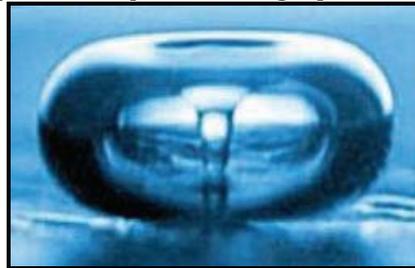
Ultrasound waves consist of expansion (rarefaction) and compression cycles. Compression cycles exert a positive pressure on the liquid and push molecules together, while expansion cycles exert a negative pressure and pull molecules apart (Figure 2). Cavities or "voids" can be generated during the expansion cycle of a sound wave, of sufficient intensity. Cavities are created in the liquid when the distance between the molecules exceeds the critical molecular distance necessary to hold the liquid together (for water molecules the critical molecular distance  $R$  is  $10^{-8}$  m).



**Figure 2: Acoustic Wave**

(Source: Moholkar, 2002)

The intensity of the sound wave needed to induce cavitation depends on the type and purity of the liquid. Pure liquids have very high tensile strength and it is difficult to produce significant negative pressures to create cavities. The theoretical pressure amplitude to cause cavitation in water is approximately 1500 bar. However, in practice acoustic cavitation occurs at far lower pressure amplitude, less than 5 bar. This is because the liquids are impure and usually contain numerous small solid particles, pre-existing dissolved gases and more especially the trapped gas-vapor nuclei, the tensile strength of the liquid is reduced as a result. These solid particles and gas bubbles represent weak points in the liquid, the place where nucleation of the bubbles occurs. A cavitation bubble in irradiated liquid continually absorbs energy from alternating compression and the expansion cycles of the sound wave. This causes the bubbles to grow in expansion cycles and contract in compression cycles. Figure 3 shows an imploding cavity in a liquid irradiated with ultrasound captured in a high-speed flash photomicrograph.



**Figure 3: High-Speed Flash Photomicrograph of Imploding Cavity**  
(Courtesy: National Center for Physical Acoustics, University of Mississippi)

Two forms of cavitation are well known: stable and transient. When bubbles undergo a stable oscillatory motion for several acoustic cycles it is called stable cavitation. A transient cavity has a lifetime of one, or at most, a few acoustic cycles, a bubble grows very rapidly to double its initial size and, finally, collapses violently in less than a microsecond. For frequencies less than 100 kHz, transient cavitation dominates. The implosion of cavities creates an unusual environment for chemical reactions. The vapor and gases inside the cavity are extremely compressed during cavity collapse. On collapse large increases in temperature and pressure are generated creating high local pressure up to 1000 atm. and a high transitory temperature up to 5000 K/5500°C inside the bubble and 2100°C in the liquid that surrounds the cavity. Such conditions are limited to a very small region and the heat produced during cavitation is dissipated very quickly (heating and cooling rates greater than  $10^9$  K/s). As a result, the surrounding liquid remains at the ambient temperature. The critical size of the bubble depends on the liquid and the frequency of the sound. At 20 kHz the size of the bubble is roughly 170  $\mu\text{m}$  and at 1 MHz it is 3.3  $\mu\text{m}$ . There are millions of these bubbles created and collapsing every second, at 20 kHz this happens 20,000 times per second. It is this transient cavitation which is responsible for process intensification (Suslick, 1989; Mason, 1999).

## 4. ULTRASONIC CLEANING

The cleaning action of ultrasonic energy is mainly due to transient cavitation. The implosion of small gas or vapor bubbles inside the cleaning liquid and near the surface to be cleaned imposes such stresses on the surface that it erodes the contaminant coat and removes the impurities (Crawford, 1963). In liquids, the collapsing bubbles remain spherical because the ultrasonic waves are uniform. However, if a transient acoustic bubble collapses near a solid boundary, the bubble will implode asymmetrically generating jets of liquid directed towards the surface of the solid boundary. The micro-jets resulting from collapsing bubbles at a solid boundary are responsible for the cleaning effect of ultrasonic waves (Suslick, 1988).

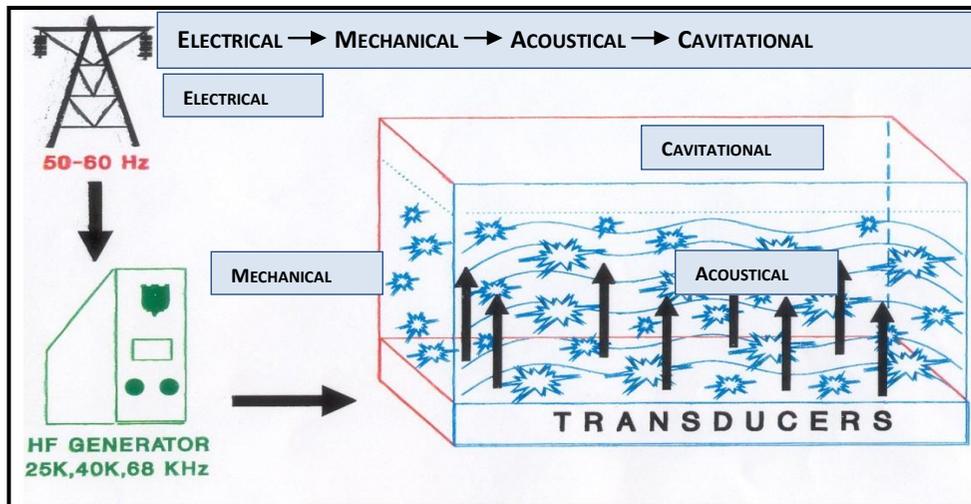
An ultrasonic cleaning system consists of four fundamental components of transducer, generator, tank and cleaning solution. Performance and reliability of the system depends upon the design and construction of the transducers and generators. The overall effectiveness of the cleaning is dependent upon the cleaning liquid. The size of the tank is dependent upon the size of the parts being cleaned. The number of transducers and generators is determined by the tank size. The choice of the cleaning solution depends on parts being cleaned and contaminants to be removed.

### 4.1 Transducers

A transducer converts high frequency electric energy into mechanical motion. When excited by an electric pulse it physically changes shape and causes the tank bottom or side to move. This creates a compression wave in the liquid of the tank. By using an electrical generator that puts out a high frequency signal (20 to 250 kHz) the transducer rapidly induces compression and rarefaction waves in the liquid. Physical mass and shape of the transducer determines its resonant point (frequency at which it will change shape). According to Newton's second law [ $F=ma$ ] force is equal to inertial mass times acceleration. Therefore a heavier faster accelerating transducer will produce more cleaning force than a lighter, slower accelerating transducer (Richardson, 1981). It is for this reason; manufacturers add resonant mass to the transducer assembly. A resonant mass is a precisely machined steel or stainless metal block, perfectly sized to resonate with the transducer output. The acceleration of the transducer makes up the other half of the law, the faster the transducer accelerates the greater amount of force it will exert. (Lower frequency have higher mass but since it has to produce fewer pulses/sec. acceleration is less and vice versa.) This law applies to all ultrasonic cleaning systems regardless of frequency (Anonymous, 1997).

### 4.2 Ultrasonic Generator

Generator energizes the transducers. It converts low frequency line power at 50-60 hertz to high frequency power at 20-80 kHz or higher, so as to match the resonant frequency of the transducer (Figure 4). The generator produces an electrical signal of high voltage and sends it to the transducer when the transducer receives the signal they respond by changing shape for as long as the signal is applied. The signal from the generator must be close to the response range of the transducer (Gooberman, 1988). Most generators are designed in modules that operate a specific amount of transducers. The most common are 250, 500, 750, and 1000Watt sizes, adding additional generator modules to the system can operate transducer stacks of any size ([t2hotline@aec.apgea.army.mil](mailto:t2hotline@aec.apgea.army.mil)).



**Figure 4: Energy Transformations**

In general, ultrasonic is used in precision cleaning as well as heavy-duty cleaning applications of complex manufactured metallic parts. It has the ability to clean in narrow crevices and small holes that are not accessible by a spray washer or other methods of cleaning. Also it is effective in removing difficult soils, such as buffing compounds and baked-on carbon. In other words, ultrasonic cleaning is especially suitable for complex part configuration and stubborn contaminants. Presently, ultrasonic cleaning finds application in areas of Healthcare and Medical which includes dental and surgical instruments, Laboratory and Pharmaceutical, Automotive and Aerospace, Industrial and Manufacturing and Light Industrial and Hobbyist such as jewelry, clocks, watches and firearms etc ([www.ultrawave.co.uk](http://www.ultrawave.co.uk)).

In analogy with its successful application in cleaning hard surfaces, its use for washing textile material has been proposed by various authors. This is supported by its application in various wet textile processes. However the mechanism responsible for process enhancement in textile is different than in other media.

**5. ULTRASONIC CLEANING PROCESS IN TEXTILES**

Cavitation collapse affects chemical processes, the possible effects of this collapse however varies in different systems. In order to scientifically understand the acoustic principles involved in a textile/water system, in particular with regard to their interactions with the fundamentals of the soil loosening and soil transport processes it is important to get a better knowledge of the mass transport phenomenon in textile materials. It is this improvement in mass transfer rate which is responsible for process enhancement and process intensification.

If mass transfer and fluid flow through textile material is accelerated, it can result in improvement in process efficiency. Several methods for this are described in literature and all of them focus on enhanced agitation of liquid; by stirring, or raising temperature of liquid etc., in some form (Matsui *et al.*, 1978; Ganguli and Eendenburg, 1980).

**Table 1: Functional Dependency of the Cavitation Energy on Some Standard Variables**

Variable	Symbol	Dependence of Bubble Energy
Frequency	$\omega$	$\omega^{-2}$
Pressure Amplitude	P	$P^{5/3}$
Surface Tension	$\sigma$	$\sigma^{1/3}$
Density	$\rho$	$\rho^{-1/2}$
Bubble Radius	R	$R^2$

There is no simple relationship between the above parameters, but this knowledge is crucial in designing experimental conditions so that the sonochemical effects are maximized.

## 6. SCOPE FOR FURTHER RESEARCH

The need for improved methods of introducing mechanical energy into the system arises from various drawbacks of current methods such as requirement of large quantities of water and energy, long process times and resultant damage to textile in these conditions. Use of ultrasound to supply this mechanical energy is a promising alternative. In a study (Warmoeskerken *et al.*, 2002) comparison of various conventional methods with ultrasonication to reduce stagnant core size in textile materials as a means of accelerating mass transfer was done and ultrasound was found to be most effective and efficient method. It was noted that rate of mass transport in textiles increased by a factor of 6, and size of the stagnant core decreased by a factor of 2.5 by application of ultrasound. Intense micro convection due to transient bubble motion driven by ultrasound, accelerated fluid flow and thus mass transfer in inter yarn and intra yarn pores of textile which is responsible for process enhancement (Moholkar *et al.*, 2003).

## 7. CONCLUSION

It has since long been speculated that using ultrasound waves could be an effective way of supplying mechanical energy for washing textiles, in analogy with its numerous successful applications in the area of hard surface cleaning. The use of ultrasonic energy for washing of textiles has been tried several times without achieving practical development. In fact, the softness of the fibres makes the cavitation to produce small erosion effect and the reticulate structure of the fabric favours the formation of air bubble layers which obstruct wave penetration. In addition, a high proportion of water with respect to the wash load and a certain water degassing is required to assure efficiency and homogeneity in the wash performance. Such requirements have hindered the commercial development of the ultrasonic washing machines for domestic purposes. For specific industrial applications, a great part of these limitations need to be overcome first before practical and easy to operate appliance is made commercially available. This paper attempted to present in detail the mechanism of soil attachment and soil release from a textile during washing. A better understanding of these Physico- chemical processes, will further the scope of use of ultrasonic energy for textile cleaning. For commercial development of the ultrasonic washing machines for domestic purposes, it is equally important to understand the mechanisms involved in textile cleaning with the use of ultrasonic energy. The article focussed on the principle of cavitation, it described phenomenon of mass transfer in textiles and the factors that affect process intensification. It also highlights the areas for future research.

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