Introduction
Washing of garments, is both an aesthetic as well as a hygienic necessity. Although essential, it is by no means an easy task. One of the challenges faced by both households as well as the commercial laundry is the removal of soil from heavily soiled areas of a garment. Despite technological strides in developing better detergents and more efficient washing machines, cleaning of heavily soiled areas like collars, cuffs in shirts and hem area of bottoms such as trousers, jeans and salwars is still a challenge. Conventional methods to clean these areas, albeit effective, are harsh, laborious and time consuming.

The cleaning action in a laundry process is the result of synergistic actions between mechanical, chemical, thermal energy and time. The three energy sources are responsible for separation of soil from the substrate and subsequently its transfer to the wash liquor; while time is an interdependent factor. To reduce the surface tension of the water and also to provide a chemical reaction between the soils to be removed from the textile substrate it is important to add chemicals which can support this mechanism, while mechanical action is necessary for physical dislodgement of solid soils (Kissa, 1981). Temperature plays an assistive role and therefore elevation in temperature (up to a point) results in cleaning process intensification by enhancing the effect of chemical and physical action.

Non-uniform initial distribution of soil in the textile results in heavily soiled areas in a garment. Cleaning of these areas effectively would require process intensification. This can be brought about by enhancing one or more of the washing parameters. Enhancement however has to be both environment as well as fabric friendly. Washing done at higher temperatures, with stronger chemicals, enhanced agitation (in the form of increased rotor speed of machines or brushing scrubbing etc.) affects the appearance and wear life of the garment. Increase in washing time would make the process cost ineffective and energy intensive and may also add to the fiber damage. Further, this damage is cumulative in nature and increases with repeated washings. Any increase in these would increase damage to the environment as well as textile substrate; on the other hand any declination in these would correspondingly reduce cleaning efficiency. Thus, there is a need to develop regimes, equipment and/or technologies which reduce these detrimental effects without affecting the cleaning performance.
Use of ultrasound for garment cleaning is one such option which is effective, fiber gentle and eco friendly. Ultrasound is high frequency sound wave inaudible to the human ear ranging from 20 kHz- 20,000 kHz. It can be used in traditional washing baths to provide an alternative to mechanical agitation to enhance process effectiveness and thereby efficaciously clean heavily soiled areas in a garment.

CURRENT SCENARIO IN LAUNDRY DEVELOPMENTS
The laundry care market is currently characterized by change in consumers’ preferences and product innovations. Concern for the environment is a significant driver for both. The issues of water and energy usage arguably are the most important long-term issues facing the household and laundry industry. Consumers and producers have moved into a more reflective and concerned phase of consumption. In response to these requirements the \textit{mantra} for the future developments is:

- \textit{Mild, green and clean}, that is mild to the skin, substrate and environmentally acceptable
- \textit{More from less} is a new notion which means improving performance which is concomitant with reducing effect on the environment
- \textit{Sustainability}, is meeting the needs of the present without compromising the ability of the future (Cahn, 2003)

Commercial laundry industry is facing challenges in the form of increasing environmental concerns and regulations, increased raw material and energy costs, high effluent treatment costs, popularity of easy care fabrics and increasing popularity of home washing machines. Households want home laundering to be a less strenuous process, with low detergent and water consumption and efficient removal of soil with minimum damage to the fabric.

In an effort to make aqueous cleaning more environment friendly, new norms and regulations for detergent formulations as well as star rating based on energy efficiency of washing machines are being implemented. The new generation high efficiency washing machines due to eco compliance are now being designed such that they are water and energy efficient (Thiry, 2008).

However, current laundring practices involving the use of reduced wash water temperatures, shorter agitation cycle, lower volume of water (for washing and rinsing)
to conserve energy and specially formulated detergents, in response to environmental concerns has aggravated the already difficult task of soil removal especially in the highly soiled areas. Lower volume of water also means higher concentration of soil in the machine which can cause problems like soil redeposition and dye transfer and dye redeposition.

Under these constraints multidirectional efforts are being made to improve existing or develop new sustainable wash systems. Some of these are- development of new technologies like self cleaning clothes (Verma, 2008); virtually waterless washing with use of plastic granules (Apparel Views, Sept, 2008); use of alternatives for detergent, and use of silver nano ions for cleaning, etc. Correspondingly, technological advancement in washing machines are also taking place, such as, substrate and soil sensitive microprocessor controlled wash cycles (which are gentle for silk and other delicate textures, normal for cotton and heavy for highly soiled articles). A detergent free washing machine was also launched by Haier, called WasH20 (www.p2pays.org).

To summarize, energy efficient and environmentally friendly wash systems are the need of the hour and technology of the future. In line with these developments use of ultrasonic energy as an alternative to conventional methods of agitation is another step in the research and development of alternative greener technologies.

ULTRASONIC ASSISTED WASHING OF TEXTILES

High frequency ultrasonic waves offer an alternative for laundry process intensification as it acts as a mechanical catalyst and accelerates mass transfer in textile washing. It is this improvement in mass transfer rate which is responsible for process intensification and enhancement in system efficacy.

The many and varied applications of power ultrasound are grouped together under the umbrella of sonochemistry. Unlike other new technologies, which require some special attribute of the system to be activated, ultrasound requires only the presence of a liquid to transmit its power (Mason and Lorimer, 1990).

Use of ultrasound has been attempted for the improvement of wet textile processes over past several decades. Improvement in energy efficiency and process times of wet textile processes such as bio-scouring, bleaching, dyeing, etc. with the application of ultrasound has also been reported.
Besides process improvement, reduction in the use of precious resources like water and energy as well as expensive and/or environmentally unfriendly reagents makes ultrasonic technology a viable option worth exploring for use in textile washing.

**SIGNIFICANCE OF THE STUDY**

Textile materials are commonly cleaned in liquid media such as water or organic solvents. However, aqueous cleaning doesn’t always suffice, as oily contaminants are difficult to remove from the fabrics because of their insolubility (Gotoh, 2010). In addition, damage to textile products such as dimensional changes by shrinkage and stretching; fibrillation, color fading; puckering and fabric handle degradation, often takes place in laundering (Sülar et al., 2009). In a wash and wear trial of polyester/cotton hospital uniforms, it was reported that 90% damage was due to washing (Bishop, 1995).

Due to these deficiencies in aqueous cleaning, solvent cleaning was successfully attempted. Organic solvents used in dry cleaning cause little damage to textiles as well as dissolve the oily contaminant. However, they are regarded as toxic substances, environmental pollutants and hazardous wastes, and their use has been restricted due to government regulations (Harada, 2005). Even the commonly used petroleum solvents and incombustible synthetic solvents have problems like low ignition point, air pollution and human toxicity (Gotoh, 2010).

Because of these factor there is a revival of interest in wet cleaning of garments and efforts are being made to improve its efficiency. Aqueous cleaning though apparently safe also affects our environment as well as textile products as it uses huge amounts of water, energy and time while generating water pollution. Energy spent on cleaning a T-Shirt during its life is twice that of what is spent during its manufacture (Thiry, 2008). Cumulative energy consumption in conventional washing is relatively very high to remove a few grams of soil. Temperature and detergent quantity consume the larger parts of cumulative energy while washing time and agitation consume only a relatively small part of the total quantity of energy (Mozes et al., 1998). Agitation therefore is a critical factor.

Effective cleaning of highly soiled areas of a garment necessitates process intensification. Conventional methods of enhancement of washing parameters are either energy intensive or labor intensive while at the same time are harmful to the fabric or
detrimental to the environment or both. Traditionally these heavily soiled areas are cleaned by enhanced agitation in the form of hand friction, scrubbing or brushing or by special wash cycle in washing machine where washing is done at high rotor speed for longer duration at higher temperature. These methods affect the appearance and serviceability of the garment, negatively.

Ultrasonic offers an energy efficient, user and fabric friendly innocuous alternative to existing practices. Despite promising research results and several patents (Appendix I), the application of ultrasonic energy for cleaning textiles, though explored, has not achieved practical development. One of the reasons is the reticulate nature of textile material. The cleaning action of ultrasonic energy is mainly due to transient cavitation which is the implosion of small gas or vapor bubbles inside the cleaning liquid and near the surface to be cleaned. Difficulties come from the softness of the fabric which causes cavitation to produce small erosion effect while the reticulate structure of textile favors the formation of layers of big bubbles that obstruct wave penetration. Therefore, the wash load has to be exposed to the ultrasonic field in a way so as to assure the production of strong transient cavitation on the fabric surface. That means the collective cavitation of a large number of bubbles in the gassy liquid (Juarez et al., 2009).

As repeatability and uniformity are very important for the textile treatment processes, the above mentioned problems have to be overcome to achieve desirable and consistent results. The lack of homogeneous cavitation in a large volume of liquid, highlights that additional research is a must to seek optimal integration of all factors of textile cleaning in concert with ultrasonic agitation. These factors need to be studied, fine tuned, synchronized and optimized.

The acoustic principles involved in a heterogeneous textile-water system are different than other media (Warmoeskerken, 1999). A scientifically based understanding of cavity behavior and washing process parameters for ultrasonic washing is needed. Maximizing cavitation of the cleaning liquid is very important to the success of the ultrasonic cleaning process. When an insufficient amount of cavitation energy is provided, undesirably long process times may be required to obtain a desired level of cleaning, or in some cases, a desired level of cleaning may not be achievable. On the other hand, excessive cavitation energy can harm the substrate. Factors affecting cavitation intensity in ultrasonic cleaning process need to be identified, so that they
can be optimized for laundry process intensification. These findings have to be then synchronized so that operating parameters and structural requirements can be identified for development and characterization of an ultrasonic system for textile washing. The assessment of effectiveness of ultrasonic cleaning prototype on the essential parameters of the washing operation has to be done for obtaining maximum cleaning results. The efficacy of this cleaning system on various substrates including delicate fabrics, various stains as well as on different soils needs to be undertaken for a comprehensive approach. The washing performance is due to mechanical and chemical action and a combination of both. The total cleaning effect can be investigated by using various kinds of soils, as some soils are sensitive to mechanical action and some to chemical action such as oxidation, solubilization and emulsification. Also, as ultrasonic washing is proposed as gentler alternative to conventional method its suitability in cleaning delicate textile substrate needs to be assessed. Progressive fabric damage due to repeated washings in conventional washing is well documented (Bishop, 1995). A comparison of ultrasonic washing with conventional washing is needed to authenticate the gentler nature of this form of agitation. Finally field trials need to be undertaken to validate the technical and economical viability of the developed prototype in a commercial set-up.

In view of the above, following **OBJECTIVES** were formulated for the study:

1. **To optimize washing process parameters for ultrasonic cleaning of highly soiled apparel.**
2. **To evaluate and compare optimized ultrasonic washing with conventional washing on following parameters: soil release, change in appearance and aesthetics, performance properties and surface characteristics with reference to repeated washings.**
3. **To study and optimize parameters affecting cavitation intensity for ultrasonic cleaning.**
4. **To design and develop ultrasonic garment cleaning prototype for optimum cleaning.**
5. **To assess the efficacy of ultrasonic cleaning prototype on various soils, substrates and stains.**