# *Materials and Methods*

The present study was undertaken to provide an alternative to mechanical agitation in the form of brushing of heavily soiled portions of a garment so as to avoid damage to the fabric. Use of ultrasonic energy is proposed as an efficient, fiber friendly and eco friendly method for cleaning highly soiled apparel.

The study was carried out with following objectives:

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 cavitational 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.

**Research Design:** Laboratory based experimental design methodology was used. Although ultrasonic cleaning is used for various substrates, the main reason for non commercialization of ultrasonic cleaning for textiles is inconsistency and non-reproducibility of results. In view of this, the first objective of the study was to optimize various factors of cleaning by ultrasonic assisted process. An ultrasonic cleaning device was fabricated and experiments were carried out at Northern India Textile Research Organization (NITRA), Ghaziabad. The optimized method was evaluated and compared with conventional washing. The effect of repeated washing on fabric properties-performance as well as aesthetics, for both methods was studied. Tests were conducted at NITRA, Ghaziabad; Indian Institute of Technology, Delhi; Department of Textile Technology, Allagappa College of Technology, Anna University, Chennai and Lady Irwin College, New Delhi. In ultrasonic assisted processes, cavitation is the main phenomenon responsible for process enhancement. Therefore, to achieve maximum cleaning, factors affecting cavitational intensity of ultrasonic cleaning system were optimized.

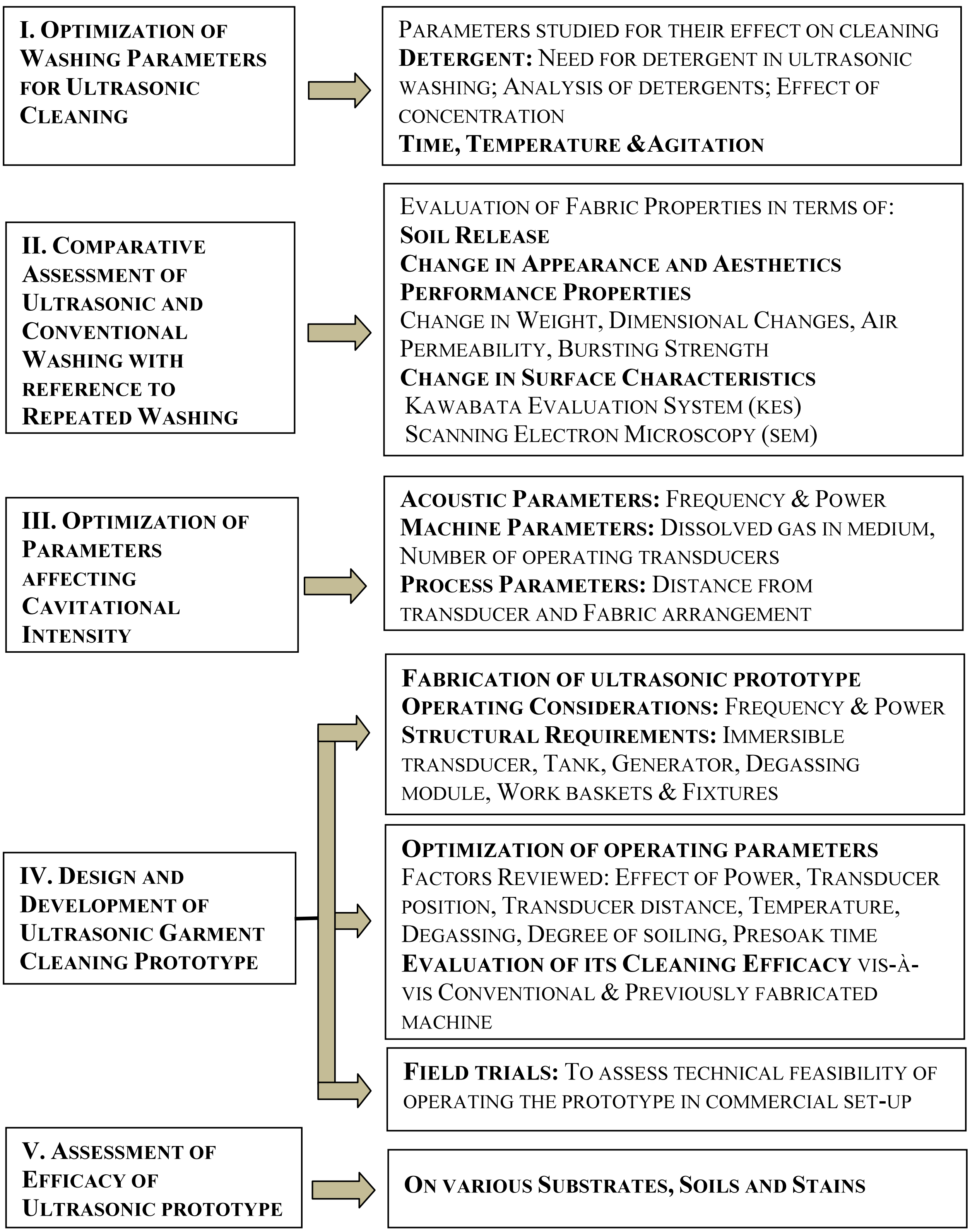



**Figure 3.1: Conceptual Framework of the Study**

Based on these findings an ultrasonic garment cleaning prototype was designed and fabricated. Once the operational parameters were optimized and its cleaning efficacy was established, the prototype was field tested at a commercial laundry and its commercial and technical feasibility was evaluated. Further, the efficacy of ultrasonic cleaning mechanism on various kinds of soils and stains as well as on different textile substrates, particularly for delicate fabrics, was studied (FIGURE 3.1).

## 3.1 OPTIMIZATION OF WASHING PARAMETERS FOR ULTRASONIC CLEANING

Various factors of cleaning for ultrasonic assisted washing of textiles, namely Detergent, Time, Temperature and Agitation were optimized.

### 3.1.1 MATERIALS

**Fabric**

100% grey cotton (plain woven) fabric with following specifications was used for the study:

| | |
|---|---|
| G.S.M. | - 137 |
| No. of ends and picks/inch | - 52 x 50 |
| Warp count | - $21^s$ |
| Weft count | - $17^s$ |
| Whiteness Index (Unsoiled fabric) | - 82.263 |

Cotton forms the major class of fabrics in the laundry, that is why it was used for test samples.

**Detergents**

For washing, standard reference detergent conforming to AATCC specifications (available under the brand name Extran® in India) and 10 varieties of commercially available washing detergents were evaluated and used (TABLE 3.1).

**TABLE 3.1: REFERENCE CODES OF COMMERCIAL DETERGENTS**

| S.No. | Brand Code | Brand Name |
|---|---|---|
| 1 | A | Surf Excel Quick Wash |
| 2 | B | Ariel Oxy Blue |
| 3 | C | Surf Excel Blue |
| 4 | D | Henko Stain Champion |
| 5 | E | Tide Plus |
| 6 | F | Nirma Blue |
| 7 | G | Rin Shakti |
| 8 | H | Sudz |
| 9 | I | Fena |
| 10 | J | Ghari |

**Chemicals**

Carbon Tetra Chloride, Coconut oil (refined and bleached), refined mineral oil, Lanolin (anhydrous), HOWCO (CG3) [10% Graphite by mass in refined mineral oil having a viscosity of 86-98 at 60°C].

### 3.1.2 METHODS

#### 3.1.2.1 PRE PREPARATION OF FABRIC

Enzymatic de-sizing of fabric was done as per IS: 199:1989 using enzyme Diastase. Fabric was immersed in the solution (M.L.R.- 1:20) containing 5g/l of active bacterial diastase, 10g/l sodium chloride and 0.1% (m/m) of a non-ionic wetting agent at 50°C at pH of 6.5-7.5. This temperature was maintained for 30 minutes while shaking the contents at intervals. After decanting the solution, fresh diastase was added and de-sizing repeated at 70°C at pH of 6.5-7.5. After decanting second time water was added and boiled for 5 minutes and subsequently washed three times with hot water. Combined scouring and bleaching was done in a bath containing 1g/l wetting agent (detergent), 2-3% Sodium Hydroxide crystals, 1-2% Hydrogen Peroxide, 0.5-1% Sodium Carbonate at 1:50 M.L.R. The treatment was carried out at boil for 2 hours.

#### 3.1.2.2 PREPARATION AND APPLICATION OF SOIL

Soil recipe was prepared as described in IS: 5785:2005, Methods for Performance Tests for Surface Active Agents, Part IV: Relative Detergency (Detailed recipe and procedure in Appendix III). The pretreated cloth was cut length wise into strips of suitable width, as per the size of the rollers. The cloth was conditioned under the standard atmospheric conditions of 27 ± 2°C and 65 ± 2% relative humidity. The fabric was soiled by passing it through padding rollers, after dipping in standard soiling mixture, at a uniform speed of 18 meter per minute. Four nips and dips were made. Fabric was turned after each passage so that the side face down is face up on second pass, and so on. The fabric was dried before subsequent pass.

As per the IS method cited above, after soiling the reflectance value of sample should be 34 ±1 but since the study was meant for heavily soiled articles, the reflectance value was maintained at a lower value of 23 ± 2. To arrive at the value of 23 ± 2 for simulation of heavily soiled areas in a garment, an average value of reflectance readings of 15 naturally soiled men's shirt, of the collar area with highest visible soiling, was taken. This value was around 23. This reflectance value in the studied fabric corresponded to whiteness index value of 49 ± 2 which was followed for the present work.

**3.1.2.3 ULTRASONIC CLEANING UNIT**

To check the viability of using ultrasonic energy for cleaning highly soiled textile substrate, preliminary work was carried out at NITRA on a commercially available ultrasonic dental scalar used for removing deposits from teeth. It had one transducer emitting 36 kHz frequency, having a limited, one liter capacity (FIGURE 3.2).

**FIGURE 3.2: ULTRASONIC CLEANING UNIT I (DENTAL SCALAR)**

The set up had following specifications:

| | | |
|---|---|---|
| Frequency | - | 36 KHz |
| Power | - | 44 watts (Average) |
| Temperature | - | 35-40°C |
| Surface Tension | - | 72 dynes/cm (water) |
| | | App. 32 dynes/cm (detergent solution) |

Once the feasibility of the study was established; an upgraded model was designed and fabricated. The fabrication was done under the supervision and guidance of Dr. J.V. Rao, Director, NITRA and a team of NITRA engineers'. This model was developed and installed at NITRA and labeled as Ultrasonic Cleaning Unit II (FIGURE 3.3). This was a multi-frequency cleaning unit with six transducers having following features:

- A stainless steel tank of 18" X 18" X 8" mounted on a stand, with 8 liter capacity
- The Ultrasonic unit had two circuits with three transducers each. Circuit 1 gave a frequency output of 31 KHz & circuit 2 gave frequency output of 39 KHz
- Option to operate all six transducers simultaneously or alternate three at a time was available
- Power as measured using power analyzer in the unit was 128 watt
- Machine control panel with controlling switches and indicators

- A stainless steel frame, length 30 cm and width 10 cm was used to hold the fabric for ultrasonic treatment. The frame was attached to a lever so that it could be moved, in and out of the tank
- Power consumption of this unit was 0.2 units per hour

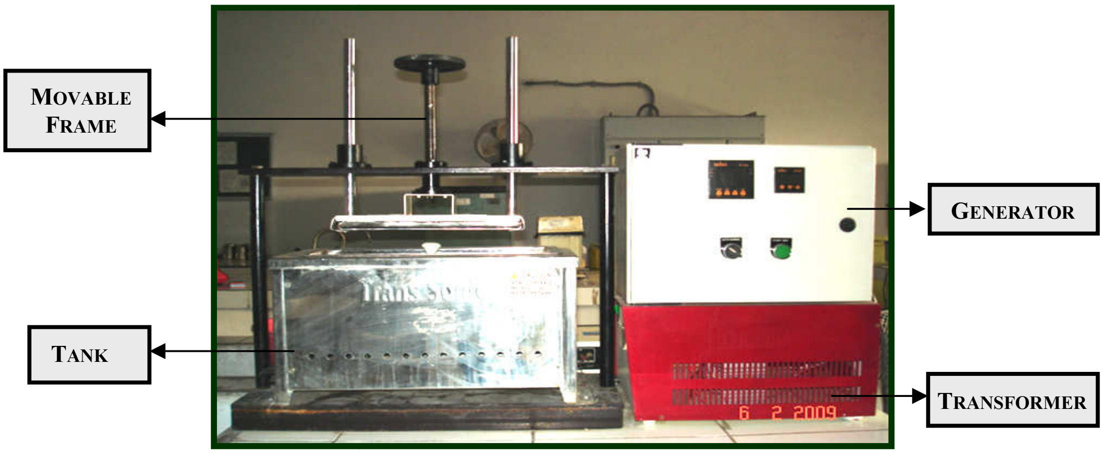



**FIGURE 3.3: ULTRASONIC CLEANING UNIT II**

### 3.1.2.4 MEASUREMENT OF REFLECTANCE AND WHITENESS INDEX OF SOILED AND WASHED SAMPLES

Instrumental analysis of soiled and cleaned samples was done using spectrophotometer interfaced with computer color matching system (CCMS). Whiteness index was measured as per Hunter's lab scale using CCMS. The illuminant used was $D_{65}$ with 10° observer. The search unit of spectrophotometer was fitted with option to include/exclude spectral component, SCE/SCI. To eliminate the effect of optical brighteners present in detergent, the measurements were taken with SCE (Spectral Component Excluded) so as to eliminate ultraviolet wavelengths. The whiteness index of unsoiled fabric, soiled and washed samples was measured taking necessary precautions to ensure the area measured after washing was exactly same as before by careful placement of the markers. For this the sample was divided into zones such that each zone corresponded to the size of the LAV aperture of spectrophotometer. 6 samples were taken (as per the size of ultrasonic tank so that the sample would be flat during treatment). Each sample was divided into 6 zones, therefore a total of 36 readings were taken for each variable.

A mean of three scans was taken for each reading for all samples.

Whiteness index readings (before and after ultrasonic treatment) were taken, percentage change in whiteness index value was used as a criterion for evaluating cleaning efficiency. Although, both reflectance value and whiteness index readings were taken, whiteness index values were tabulated and analyzed.

For evaluating cleanliness besides using CCMS, digital scanner (Hewlett Packard Inc. model scan jet) was also used. To quantify the cleaning effect, samples were scanned to obtain 8-bit grey scale bitmap image. The grey scales of the bit map image varied from 0 to 255; with 0 and 255 corresponding to the darkest and the whitest pixel respectively. This image was then processed using Corel Photo Paint software (version 12). During the image analysis two main aspects were analyzed: the average grey scale of all the pixels and the standard deviation of the grey scales of all the pixels (Moholkar *et al.*, 2003). This method however could not be used for the subsequent work. This method would be of use if the entire sample area is uniformly soiled and cleaned where as in case of garments there are adjacent pockets of heavily and lightly soiled areas. During image analysis this method gave an average grey scale of the total pixels ignoring degree of soiling (white/dark) before and after the various treatments making comparison difficult. That is why the data obtained by this method was ignored while tabulating and analyzing.

### 3.1.3 EFFECT OF WASHING PROCESS PARAMETERS ON CLEANING

To optimize the washing conditions for ultrasonic cleaning, effect of washing process parameters namely type and concentration of detergent, time, temperature and nature of agitation were studied. For all optimization experiments ultrasonic unit II was used. The tank was filled with 6 liters of ordinary tap water and specified amount of detergent was added. For the purpose of comparison, cleaning was also done in the absence of ultrasonic energy, other conditions being identical i.e. the samples were immersed in the ultrasonic tank with detergent solution for specified time but no energy was supplied (control samples).

Since the aim of the study was to replace pretreatment like brushing of heavily soiled portion of garment before loading in a washing machine, optimization was done only for pretreatment parameters. The pretreatment (control/ultrasonic cleaning/brushing) was not followed by machine washing, to avoid interference with results.

#### 3.1.3.1 EFFECT OF DETERGENT

Ultrasonic being another form of energy, it was important to identify its role in cleaning as supplementary or substitute to existing parameters, specifically chemical energy (detergent). The enhancing effect of sonication vis-à-vis chemical formulation for textile cleaning was studied. Samples were soiled and washed in presence/absence of ultrasonication and detergent. Samples were coded as:

| Sample | Code | Ultrasonic | Detergent |
|---|---|---|---|
| Control | C | x | x |
| Sonicated sample without detergent | US | √ | x |
| Sonicated sample with detergent | USD | √ | √ |
| Non-Sonicated sample with detergent | NUSD | x | √ |

Fabric was soiled as per IS: 5785:2005 and samples were soaked in water/ standard detergent (5g/l) at ambient temperature. Selected samples were exposed to ultrasonic energy for 1minute while other samples were kept soaked in water /detergent solution during this 1 minute duration. Measurement was done as per section 3.1.2.4. Whiteness index values of the soiled and treated samples were noted. Percentage change in whiteness index values was plotted and interpreted. Findings clearly established the need for using detergent along with ultrasonic for optimum cleaning results.

**3.1.3.1.1 ANALYSIS AND EVALUATION OF COMMERCIAL DETERGENTS**

To identify the suitable detergent for ultrasonic cleaning, standard prescribed detergent along with various commercial detergents were studied. A detailed analysis of standard and ten popular commercial brands of detergent covering all price points was undertaken. The most effective commercial detergent formulation found along with standard detergent was then studied at various concentrations.

A detergent is a synthetic surface active agent that consists of a surfactant and materials like fillers, boosters, builders etc. Over the years many new components have been included in its formulation for performance enhancement. For a practical and realistic evaluation of detergent quality, physico-chemical analysis, along with performance tests were also done. The effect and nature of surface active agents can be measured in terms of basic physical measurements such as surface tension, viscosity etc. or in terms not involving physical units which are called gross effects. As the utilization and performance of surface active agents is based on their gross effects, they were assessed in terms of these properties. The detergents were analyzed and compared in terms of their basic composition, additives present and their performance as summarized in TABLE 3.2 (Details of procedures in Table I, Appendix IV).

**TABLE 3.2: ANALYSIS OF COMMERCIAL DETERGENTS (DETAILED PROCEDURES OF PROPERTIES TESTED CITED IN APPENDIX IV)**

| S.No. | Property Tested | Test Method |
|---|---|---|
| COMPOSITION | | |
| 1. | **pH** | The alkaline pH improves loosening of soils; it neutralizes the acidic sebum fatty soils thereby making the detergent more effective. Test Method adopted from IS:4955:2001 was used for pH determination |
| 2 | **ALKALINITY** | Total Alkalinity gives an idea about the buffering capacity of the detergent so that the pH of the wash liquor remains in optimum detergency range. It was tested as per IS: 4955:2001 [Annex F clause 8.1, Table1, Sl. No. (iv)]. |
| 3 | **NATURE OF SURFACE ACTIVE AGENT** | Ionic nature of various detergents was determined by treating them with a colored reagent of the opposite ionogenic type followed by addition of a non-polar liquid such as chloroform and shaken. The appearance of a particular colored molecule in the organic layer showed presence of anionic/ cationic or non-ionic surface active agent (Rosen & Goldsmith, 1960). |
| 4 | **TOTAL ACTIVE MATTER (%MASS)** | Total active matter is directly related to cleaning efficiency. Higher % of active ingredient would improve detergency and give good value for money. Tested as per IS: 4955: 2001[Annex B, Clause8.1; Table1, Sl No. (i)]. |
| ADDITIVES PRESENT | | |
| 5. | **PRESENCE OF OXIDIZING AGENTS** | Presence of oxidizers was tested as they assist in cleaning by means of bleaching and help in breaking down organic compounds (Bhattacharya, 2009)<br>Tested as per method adopted from IS: 286-1978. |
| 6. | **PRESENCE OF BORATE** | Presence of borate in detergent formulation was checked as per IS-286-1978. |
| 7. | **PRESENCE OF PEROXY COMPOUNDS** | Hydrogen Peroxide is converted by alkaline medium to the active intermediate $H_2O_2$ anion.<br>$H_2O_2 + OH^- \rightleftharpoons H_2O + HO_2^-$<br>The perdoxyl anion ($HO_2^-$) oxidizes bleachable soils and stains (Bhattacharya, 2001). It was tested as per method described in BTRA Chemical Testing Manual (method adopted from BS: 3762 (Part2) -1989, Analysis of Formulated Detergents-Qualitative Test Methods). |
| 8 | **PRESENCE OF ACTIVE OXYGEN** | Percentage active oxygen is an indicator of bleaching efficacy of respective detergent (Rosen & Goldsmith, 1960). |
| 9 | **PRESENCE OF FLORESCENT BRIGHTENING AGENTS** | Fluorescent shine in a source of ultraviolet light in a dark room indicated presence of fluorescent brightening agents (F.B.A's). |
| 10 | **PRESENCE OF ENZYMES** | The catalytic nature of enzymes makes them highly efficient as detergent components to digest proteins, fats or carbohydrates in stains or to modify the fabric feel.<br>Tested as per Table 8.2, BTRA Chemical Testing Manual, 1985). |

| S.No. | Property Tested | Test Method |
|---|---|---|
| PERFORMANCE TESTS | | |
| 11 | **Relative Wetting Power** | Surfactants lower surface and interfacial tensions which helps wash liquor to penetrate better, get under the soil and help lift it from substrate.<br>This was tested as per IS: 5785 (Part V)-2005. |
| 12 | **Relative Dispersing Power** | After the breakdown of soil into fine particles, the detergent helps in maintaining a soil/liquid matrix as dispersion or colloidal solution, preventing agglomeration (Kissa, 1981). Detergents with higher dispersing power therefore would remove soils better. Dispersing power of various detergents was compared.<br>As per IS: 5785(Part I)-2005. |
| 13 | **Relative Foaming Power** | It was tested as per IS: 5785 (Part III)-2005. |
| 14 | **Minimum Amount of Detergent Required to Attain Lather** | This is an indicator of amount of softener present in detergent. The lesser the amount of detergent required, higher is the amount of softeners in detergent, that would give good detergency even in hard water. Tested as per BS: 3762 (Part 2)-1989. |
| 15 | **Color Fading** | A specimen of textile was mechanically agitated under conditions specified in Table 2, Test number B, ISO 105-C10: 2006(E). The change in color of the specimen was assessed in reference to the original fabric with grey scale and numerical ratings were given for comparison.<br>Assessed as per ISO 105-C10: 2006(E). |
| 16 | **Stain Removal** | Work was also carried out with four common stains- Tea, Coffee, Pickle and Indian Curry. Fabric samples were artificially stained (two conditions were tested 12 hrs. and 24 hrs. stain) and then washed under standard conditions in laundrometer. The samples were evaluated using grey scales for staining. |
| 17 | **Relative Detergency** | Relative detergency is affected by all the above mentioned constituents and therefore was of paramount importance in identifying the suitable commercial detergent. The detergency value is expressed as a percentage of soil removal and was calculated from following equation:<br>$$\%\ \text{Soil Removal} = \frac{A - B}{C - B} \times 100$$<br>where<br>A = Reflectance of soiled fabric after washing<br>B = Reflectance of soiled fabric before washing<br>C = Reflectance of white fabric before soiling<br>Tested as per IS: 5785 (Part IV)-2005. |

Detailed assessment of detergents on the previously cited parameters was done that helped not only in identifying the most effective commercial formulation for washing but also in highlighting the ingredients responsible for its comparatively superior performance.

The most effective commercial detergent was used in subsequent experiments. As the main objective of the study was to replace conventional pretreatments like brushing, scrubbing etc. that are in practice for cleaning heavily soiled apparel with ultrasonic cleaning; use of commercial detergent therefore helped in simulation of the home laundry conditions closely.

#### 3.1.3.1.2 EFFECT OF DETERGENT CONCENTRATION (STANDARD AND COMMERCIAL)

The standard detergent along with the most effective commercial detergent was tested and evaluated for soil release at following concentrations – 3, 6, 9, 12, 15 and 18g/l. Work was carried out at ambient temperature for 1 minute ultrasonication time. Whiteness index readings were measured before and after washing as outlined in section 3.1.2.4. Percentage change in whiteness index readings was used as evaluation criterion. The results were tabulated and statistically analyzed as per section 3.1.3.5.

### 3.1.3.2 EFFECT OF TIME

To optimize time for ultrasonic cleaning, standard soiled samples were exposed to ultrasonic treatment for 1, 3, 5, 7, 9 and 11 minutes. Work was carried out using standard and commercial detergent at previously optimized concentration of 3g/l. Although initial experiments were also carried out with 30 second ultrasonic treatment time, due to insufficient cleaning, readings were not considered for further work. The optimum time for ultrasonic treatment after statistical analyses was 1 minute. Therefore, for subsequent experiments, soiled portions were subjected to ultrasonic pretreatment for only one minute.

### 3.1.3.3 EFFECT OF TEMPERATURE

To optimize temperature standard soiled samples were washed with standard and commercial detergent (3g/l) at 30°C, 40°C, 45°C, 50°C, and 60°C. Experiments were conducted both in presence and absence of ultrasonic energy. Ultrasonic energy was supplied for 1 minute (section 3.1.3.2). On comparative assessment 40°C temperature was found optimum for both detergent systems and for subsequent experiments both for presoaking as well as washing this temperature was maintained.

### 3.1.3.4 EFFECT OF AGITATION

Agitation is the final key piece of the aqueous cleaning process. The amount and type of mechanical energy employed can affect the efficiency of cleaning, which in turn has to be decided keeping in mind the nature of the contaminant and tolerance of the substrate. In the present work the aim was to substitute mechanical energy employed in the form of scrubbing or brushing of highly soiled areas in a garment with ultrasonic energy before loading it onto a washing machine. For this, experiments were conducted at optimized conditions of time, temperature and concentration with both commercial and standard detergent. Collar samples with inter-lining were stitched and given to 12 subjects to wear around the neck, sometimes on top of the existing collar, as the case may be, and held in place with the help of paper clips. The soiled collars returned after a standard day's wear were used for the study. This was repeated for 3 days to collect the requisite number of samples. PLATE 3.1A,B shows stitched collars, before and after soiling. Samples were exposed to ultrasonic treatment in the unit II described in section 3.1.2.3. To avoid any bias in simulating conventional washing, mechanized brushing (section 3.1.3.4.1) was carried out under similar conditions as ultrasonic treatment. Whiteness index was measured for evaluation as outlined in section 3.1.2.4. Statistical analysis of data was done to see if there is any significant difference in cleaning efficiency of both agitation methods.

#### 3.1.3.4.1 AUTOMATED SCRUBBING TO SIMULATE CONVENTIONAL WASHING

To simulate brushing action, as a pretreatment for heavily soiled areas in a garment before loading it in a washing machine, wet abrasion scrub tester was used with minor modifications (PLATE 3.1C,D). It is also called double headed washability tester and is designed to provide an accelerated method of determining abrasive wear resistance of coatings and abrasive effect of cleaning compounds. For the present study the hog bristle brush was replaced with nylon bristle brush which is generally used for fabric cleaning. The brush applied a load of 500 ± 15g and had a scrub rate of 37± 1 cycle per minute. It also had a pump to supply reagent during operation (PLATE 3.1D). Soiled collars were lengthened by adding extra strips of fabric on both sides to facilitate securing on to the machine while brushing (Machine details in Appendix V). Brushing was carried out for 1 minute with both standard and commercial detergent at 3g/l concentration, 40°C after soaking for 5 minutes. Whiteness index values before and after brushing were noted, tabulated and statistically analyzed.

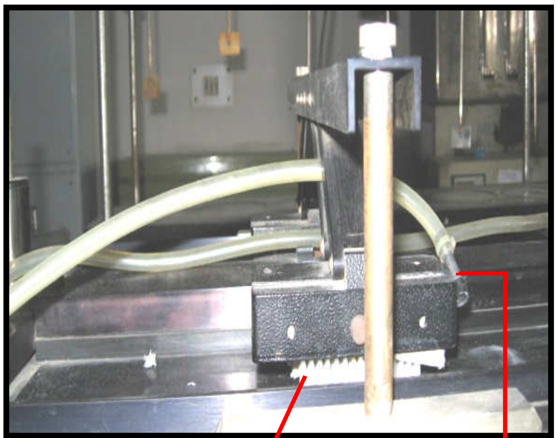
## PLATE 3.1

### SAMPLES AND EQUIPMENT USED TO STUDY EFFECT OF NATURE OF AGITATION ON CLEANING

A. UNSOILED COLLAR

B. SOILED COLLAR


C.



D.

BRUSH FOR SCRUBBING

FOR DETERGENT SUPPLY

WET ABRASION SCRUB TESTER

### 3.1.3.5 STATISTICAL ANALYSIS

Detergent concentration, time, temperature and agitation are much studied parameters for their effect on cleaning in conventional laundry method. It was important to first confirm the effect of these parameters for ultrasonic cleaning. Change in whiteness index values subsequent to ultrasonic agitation for all four parameter variables was tabulated and percentage change was statistically analyzed. To see if variation in the parameters studied significantly affects the cleaning, variation analysis ANOVA for repeated measurements to test for effect of between subjects was undertaken. Once ANOVA confirmed that there is significant difference in group means due to variation in process conditions, it was followed by Tukey Post hoc test for ANOVA to identify the groups which were significantly different. The significant variable was further compared to all other groups by employing Students' t- test for independent group means for identifying the optimum conditions for ultrasonic washing.

The experiments in this section helped in identifying optimum wash conditions for ultrasonic cleaning. The experiments also indicated that ultrasonic agitation can efficiently clean and effectively substitute conventional methods of cleaning highly soiled areas in apparel.

## 3.2 COMPARITIVE ASSESSMENT OF ULTRASONIC AND CONVENTIONAL WASHING WITH REFERENCE TO REPEATED WASHING

In the present study the effect of different pretreatments on fabric properties and appearance after repeated washings was explored. Two pretreatment methods: Ultrasonic agitation and mechanical agitation in the form of brushing along with control samples (no pretreatment only machine washed) were compared on following parameters: soil release, change in appearance and aesthetics, change in surface characteristics and change in performance related properties with reference to repeated washings up to 50 washes.

### 3.2.1 MATERIALS

**Fabrics**

To see the effect of repeated washings clearly, 100% grey cotton, plain weave fabrics of low (delicate) and medium weights, with following specifications were studied.

Fabrics were desized, scoured and bleached (section 3.1.2.1). Whiteness Index and reflectance of unsoiled fabric was measured (section 3.1.2.4)

| **Property** | **Fabric 1 ($F_1$)** | **Fabric 2 ($F_2$)** |
|---|---|---|
| G.S.M. | 66 | 123 |
| No. of ends and picks/inch | 88×88 | 92×88 |
| Warp count | $67^s$ | $40^s$ |
| Weft count | $69^s$ | $40^s$ |
| Whiteness Index (Unsoiled ) | 72.9 | 78.7 |
| Reflectance Value (Unsoiled) | 52.48 | 61.45 |

### 3.2.2 METHODS

#### 3.2.2.1 SAMPLE PREPARATION

Samples were cut from both fabrics and coded (TABLE 3.3) depending on the pretreatment and fabric type. Whiteness Index and reflectance of soiled fabrics was measured (section 3.1.2.4).

**TABLE 3.3: REFERENCE CODES OF SAMPLES**

| **Sample code** | **Sample** | **Pre-treatment** | **Fabric Type** | **Number of Washes** |
|---|---|---|---|---|
| Co $F_1$10w,Co $F_1$20w, Co$F_1$30w, Co $F_1$40w & Co$F_1$50w | Control | No Agitation | Fabric 1 | Fabric1- Control sample only machine washed |
| Co$F_2$10w, Co$F_2$20w, Co$F_2$30w, Co$F_2$40w & Co$F_2$50w | Control | | Fabric 2 | Fabric2-Control sample only machine washed |
| Cn$F_1$10w, Cn$F_1$20w, Cn$F_1$30w, Cn$F_1$40w & Cn$F_1$50w | Conventional washing | Scrubbing with brush | Fabric 1 | Fabric1-Brushed and machine washed |
| Cn$F_2$10w, Cn$F_2$20w, Cn$F_2$30w, Cn$F_2$40w & Cn$F_2$50w | Ultrasonic washing | | Fabric 2 | Fabric 2-Brushed and machine washed |
| US$F_1$10w, US$F_1$20w, US$F_1$30w, US$F_1$40w & US$F_1$50w | Ultrasonic washing | Ultrasonic Agitation | Fabric 1 | Fabric1- Exposed to ultrasonic and machine washed |
| US$F_2$10w, US$F_2$20w, US$F_2$30w, US$F_2$40w & US$F_2$50w | Ultrasonic washing | | Fabric 2 | Fabric2-Exposed to ultrasonic and machine washed |

*10w, 20w, 30w, 40w and 50w refer to corresponding number of washes

#### 3.2.2.2 PRETREATMENT AND WASHING

A total of 330 samples, 55 samples per treatment per fabric were cut and soiled with standard soiling mixture (section 3.1.2.2). After presoaking the samples in commercial detergent for 5 minutes at optimized concentration and temperature, they were exposed to various pretreatments. Ultrasonic treated samples were washed in ultrasonic cleaning unit II for 1 minute (section 3.1.2.4); for simulating conventional washing, samples were exposed to automated scrubbing for 1 minute (section 3.1.3.4.1) under standardized conditions. Control samples were only presoaked and not exposed to any agitation. All the samples were then washed in a domestic washing machine (IFB, fully automatic, front loading, horizontal rotating drum) as per ISO: 6330: 2000(E) Procedure No.2A (Details of procedure in Appendix VIII). This constituted one washing cycle. This soiling, pretreatment followed by machine wash was repeated up to 50 cycles for both fabrics. Samples were withdrawn after 10, 20, 30, 40 and 50 washes for testing various properties. As samples were withdrawn for evaluation replacements were added so that the load remained constant.

Evaluation was done in terms of soil release, change in appearance, change in surface characteristics' and change in performance properties.

### 3.2.3 SOIL RELEASE

The degree of Whiteness and Percentage Reflectance of the soiled, unsoiled and washed sample was measured instrumentally (Section 3.1.2.4). Soil removal was calculated as per IS: 5785 (Part IV)-2005. The detergency value expressed as a percentage of soil removal was calculated from following equation:

$$\%Soil\ Removal = \frac{A - B}{C - B} \times 100$$

Where

A = Reflectance of soiled fabric after washing

B = Reflectance of soiled fabric before washing

C = Reflectance of white fabric before soiling

### 3.2.4 APPEARANCE AND AESTHETICS

From a consumer's point of view the most important considerations after washing would be level of cleaning achieved and the general appearance of the article.

#### 3.2.4.1 APPEARANCE OF FABRIC AFTER REPEATED HOME LAUNDERING

It was evaluated using AATCC test method 124 - 2005. This test method is designed to evaluate the smooth appearance of flat fabric specimens after repeated home laundering. In this method, smooth appearance is defined as the visual impression of planarity of a specimen quantified by comparison with a set of reference standards. Flat fabric specimens subjected to various washing methods were compared. Precautions to avoid dryer creases as outlined in the method were followed. Evaluation was performed using standard lighting in the viewing area by rating the appearance of specimens in comparison with appropriate reference standards (TABLE 3.4). An attempt to correlate surface wrinkling and dimensional shrinkage was also made.

**TABLE 3.4: FABRIC SMOOTHNESS GRADES BY SA REPLICA EQUIVALENTS (AATCC TM 124-2007)**

| Grade | Description |
|---|---|
| SA-5 | Very smooth, pressed, finished appearance |
| SA-4 | Smooth, finished appearance |
| SA-3.5 | Fairly smooth but non-pressed appearance |
| SA-3 | Mussed, non-pressed appearance |
| SA-2 | Rumpled , obviously wrinkled appearance |
| SA-1 | Crumpled, creased and severely wrinkled appearance |

#### 3.2.4.2 VISUAL EXAMINATION

For subjective evaluation, visual examination of samples after various pretreatments and washes was done under standard lighting conditions on a flat area. It was done to check for

- Fuzziness

After textiles are washed and dried many times, small micro fibrils form on the surface of the cellulose fibers. The micro fibrils give the fibers a hairy or '*fuzzy look*'. These tiny 'hairs' disperse incoming light, making the fabric colors look dull.

- Yarn breakage
- Tears, holes etc. after repeated washings
- Color change with respect to the color of the original fabric
- Surface damage

A 5 point rating scale was developed; on this continuum a rating of 5 meant highly satisfactory appearance while 1 meant highly dissatisfactory appearance. Visual examination was carried out by 3 independent observers; the research assistants employed in textile research laboratory, NITRA with textile testing experience between 8-17 years. 11 samples were withdrawn after 10, 20, 30, 40 and 50 washes for all three pretreatments (11 samples x 3 pretreatments x 5 washes). This was done for both fabrics. These samples were rated by three evaluators, ratings were recorded, their mean values were calculated and tabulated to draw inferences.

- Pilling

Pilling was assessed by comparing to standards prescribed in SP15 (Part 2): 2000, method adopted from IS: 10971:1984. The appearance of the washed samples was compared with a set of 5 photographic standards, 110mm x 95mm in size numbered 1 to 5 showing varying degree of pilling as outlined below.

Rating 1 Very severe pilling
Rating 2 Severe pilling
Rating 3 Moderate pilling
Rating 4 Slight pilling
Rating 5 No pilling

Numerical ratings were compared to illustrate the effect of pretreatment method on fabric aesthetics with reference to repeated washing as well as fabric weight.

### 3.2.5 PERFORMANCE PROPERTIES

Properties which can affect the performance and serviceability of an apparel item, such as dimensional change, loss in strength etc., for various pretreatments and washes, were evaluated.

#### 3.2.5.1 CHANGE IN WEIGHT

Change in weight was determined for the standard fabric specimen after designated washing cycles by calculating mass per unit area of fabrics as per IS :1964:2001 (Second Revision) Method A–Conditioned Mass Method was followed. Material was conditioned in standard atmospheric condition (65±2% relative humidity and temperature 27±2°C) and then the mass was determined. Before and after wash weights were compared to calculate the loss in weight and plotted against number of wash cycles. Percentage weight loss after 10, 20, 30, 40 and 50 washes for various pretreatment methods as well as for both fabrics was compared.

#### 3.2.5.2 DIMENSIONAL CHANGES IN FABRICS AFTER HOME LAUNDERING

Fabric shrinkage/elongation after repeated washing was tested as per AATCC Test Method 135-2004. This method outlines the procedure for sample preparation, placement of benchmarks before laundering, method for washing, drying and ironing. Sample preparation was done as per section 6.2.3.2 of the method. After conditioning, the sample was placed on a flat area and the distance between each pair of benchmark to nearest mm is measured. Percentage dimensional change (length, width and area) after 10, 20, 30, 40 and 50 washes for both fabrics and various pretreatments was reported.

Average % Dimensional change (length / Width) = 100(B-A)/A

where

A=Average original dimension

B=Average dimension after laundering

Mean percentage area dimensional changes were also calculated as per the following equation:

$$\Delta A\% = \Delta L\% + \Delta W\% - \frac{(\Delta L\% \times \Delta W\%)}{100}$$

where

ΔA% = Percentage Area Dimensional Change

ΔL% = Percentage Length Dimensional Change

ΔW% = Percentage Width Dimensional Change **(**Hurren *et al.*, 2008**)**

**3.2.5.3 AIR PERMEABILITY**

Air permeability is the measure of resistance of fabrics to the passage of air through them. It was measured on WIRA Air Permeameter in accordance with IS: 11056: 1984 after 10, 30, and 50 washes for both fabrics. This method is based on the measurement of the rate of air flow through a given area of fabric by a given pressure drop across the fabric. According to this standard, air permeability is the volume ($cm^3$) of air passing through 1$cm^2$ of fabric per second at a pressure difference of 1 cm head of water. Samples were conditioned at 65 ± 2% relative humidity and 27±2°C temperature. Conditioned samples were mounted between the clamp and circular orifice with sufficient tension to eliminate wrinkles. Air was forced through the fabric and the rate of flow was adjusted till pressure drop of 1 cm water head across fabric was indicated. Rate of air flow in $cm^3$/s was noted. 10 such readings were taken. This was repeated for all treatments, washes and fabrics.

Rate of flow of air per $cm^2$ of fabric in $cm^3$/s was calculated by the following formula:

$$R = \frac{r}{A}$$

Where

R = rate of flow of air/ $cm^2$ of fabric in $cm^3$/s

r = mean rate of flow of air in $cm^3$/s

A = area $cm^2$ of fabric under test in $cm^2$

**3.2.5.4 BURSTING STRENGTH**

It is defined as the maximum fluid pressure applied to a circular specimen in distending it to rupture. It is expressed in kgf/$cm^2$ or kN/$m^2$. This testing was carried out on Tru Burst 2, (James H. Heal & Co Ltd., Halifax, England) as per ASTM D 3786-06 in the Textile testing laboratory at I.I.T. Delhi. Bursting distension is the maximum height in mm achieved at the time of bursting by the centre of the upper surface of the specimen during the test. A specified area of the sample of conditioned fabric to be tested was clamped in tensionless state over an elastic diaphragm. An increasing fluid pressure was applied to the underside of the sample till it bursts. The test was repeated at 10 other places on test sample. The bursting strength and bursting distension were noted. Comparative analysis of data to assess loss in strength after 10, 30 and 50 washes vis-à-vis various treatments and fabrics was done.

### 3.2.6 SURFACE CHARACTERISTICS

For objective evaluation of the effect of various pretreatments on surface properties of fabric after repeated washing, Kawabata Evaluation System (KES) for measurement of hand/feel along with Scanning Electron Microscopy (SEM) for highlighting surface changes was undertaken.

#### 3.2.6.1 KAWABATA EVALUATION SYSTEM (SURFACE FRICTION TESTER)

Kawabata evaluation system (KES) was used to make objective measurements of hand properties. It is a systematic method of measuring the surface and mechanical properties of fabrics using very sensitive testing devices developed by Dr. Sueo Kawabata, Head of Polymer Chemistry at Kyoto University, Japan. The initial work started in 1968 and the system has been commercially available in its present form since 1978 (Kawabata, 1973; 1980; Matsudaira *et al.*, 1985).

The Kawabata system of instruments, featured in the fabric hand laboratory, measures mechanical properties of textile fabrics that correspond to the fundamental deformation of fabrics in hand manipulation and predicts the aesthetic qualities perceived by human touch. The KES includes five highly sensitive instruments that measure fabric bending, shearing, tensile and compressive stiffness, as well as the smoothness and frictional properties of fabric surface. It measures fabrics mechanical and surface properties at load level typical of normal handling and end use applications.

For the present work Surface Friction Tester was used; which is one of the testers of the KES-FB series (Kawabata's Evaluation system) and is the one designed to measure surface properties of fabrics. This instrument is equipped with two probes to measure the friction and the surface roughness of tested fabrics respectively (FIGURE 3.4). To measure surface friction, a sensor, is placed on the fabric surface applying a total load at 50gf. To measure surface roughness the vertical sensor touches the fabric with a constant force of 10gf.

In this instrument, the coefficient of friction and roughness was determined by passing a metal probe over a mounted swatch of fabric. Following measurements were taken.

**MIU (Coefficient of Friction) -** This is a measure of force in horizontal direction and a detachable arm with load is pressed on the sensor which measures the force. MIU is developed from zero and measures MIU (Forward) and MIU (Backward). MIU(Total) = MIU (F) + MIU (B) Depending on the coefficient of friction a force F is generated and measured at every 1/100 mm (30mm fabric swatch is clamped such that 5mm is utilized in clamping on each side so the actual area measured is 20mm). The reading is therefore an average of about 4000 readings.

It measures the resistance/drag of the sample and has values ranging from 0 to 1, higher values indicate greater friction.

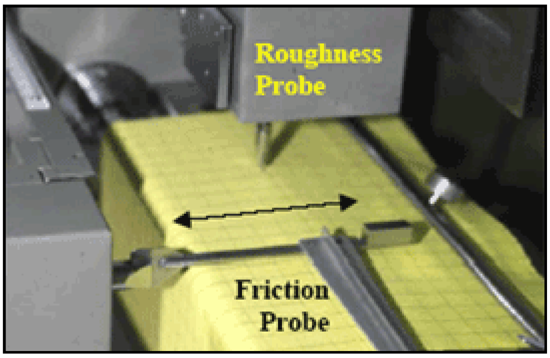



**FIGURE 3.4: KAWABATA EVALUATION SYSTEM (KES-FB4 SURFACE TESTER)**

(Source: http://www.tx.ncsu.edu)

**MMD (Mean Deviation in MIU) -** This is variation in friction (Stdandard Deviation) over this 20mm area.

**SMD (Geometrical Roughness) -** A sample is clamped at both ends onto the machine, which gives it a fixed tension. One end of the sample is fixed on the winding drum by a clamp 'A' and the other end is held by clamp 'B' onto the loading arm. A weight is placed on the loading arm and this tension is passed onto the fabric clamped in clamp 'B'. The winding drum turns at a speed of 1 mm per second by means of a synchronous motor and this moves the sample.

When the sample has moved 3.0 cm, the motor reverses to return to the starting position at the same speed. The direction of movement and the distance are measured by a potentiometer, which converts the displacement into an output voltage.

As the sample is moved forward and then backward by the rotation of the drum, different areas of the fabric pass under the surface roughness detector probe. Another transducer detects the vertical movements of the probe caused by the roughness of the sample surface. These variations in the surface height are averaged out and displayed at the end of the test.

The physical location of the probe can be moved across the width of the fabric so that fabric roughness can be measured at different areas. The detection of the surface roughness is very sensitive and the maximum resolution of the fabric roughness probe is 0.5 µm (Murugan and Nayar, 2010).

The tests were carried out at Department of Textile Technology, Allagappa College of Technology, Anna University at Chennai.

The data obtained for all pretreatments 10, 20, 30, 40 and 50 washes and both fabrics was statistically analyzed to see if there is significant difference between various pretreatments with reference to repeated washings. Variation analysis (ANOVA) was done to delineate the effect of number of washes and washing method on surface properties. For all the three washing methods; control, ultrasonic and conventional ANOVA was done to see if change in number of washes correspondingly caused variation in MIU and SMD. This was followed by one way variation analysis to see effect of washing method on these two properties irrespective of number of washes. The findings of ANOVA were corroborated by employing independent Students t- Test.

**3.2.6.2 SCANNING ELECTRON MICROSCOPY (SEM)**

To further highlight the fabric and yarn damage due to conventional pretreatments like brushing specially after repeated washings, the scanning electron microscopy was conducted. Samples of both fabrics exposed to various pretreatments at the end of 20 and 50 washing cycles were scanned to get the scanning electron micrographs. The basic function of scanning electron microscope is to produce on a T.V. monitor, an image of 3-D appearance derived from the action of an electron probe scanning the surface of a specimen. The instrument has a continuously variable magnification in the range X10- X 300,000. The samples were scanned without coating, which gave better idea about the damage, for the present study. Images at 500X-10,000X magnification were taken. The samples were observed using ESEM: FEI, Quanta 200F (Netherlands. EDS, Oxford Instruments, UK), in Project SMITA laboratory (Smart and Innovative Textiles) at I.I.T. New Delhi. The micrographs were carefully observed and compared for fiber, yarn and fabric damage at 2000, 5000 and 10,000 magnification.

From the experiments above, a comparison was drawn between conventional and ultrasonic pretreatment in terms of change in fabric properties after successive washes. Contribution of influencing factors like fabric characteristics, number of washes as well as type of pretreatment was studied. Comparison of pretreated samples with control (no pretreatment, only machine wash) was done to observe additional damage, if any, due to ultrasonic pretreatment of fabrics.

## 3.3 OPTIMIZATION OF PARAMETERS AFFECTING CAVITATIONAL INTENSITY FOR ULTRASONIC CLEANING

For efficient textile wet processes, it is of paramount importance to optimize cavitation intensity (Moholkar *et al.*, 2003). Review revealed various factors like frequency, power, proximity of the substrate to the transducer, amount of gas present in the liquid etc. (Pohlman *et al.*, 1972; McQueen, 1986; Niemczweski, 1980, 2003, 2007) can affect the intensity of cavitation; these factors being interlinked and interdependent. These factors have been studied for cleaning of metallic parts etc. in the industry using industrial solvents. As the present work was intended for cleaning heavily soiled areas in a garment in the presence of a commercial detergent, these factors were reviewed, studied and optimized; as higher cavitational intensity would correspond to higher level of cleaning. These variables were categorized under Acoustic, Machine and Process parameters. Samples were soiled as per section 3.1.2.2 and measurements were done as per section 3.1.2.4; effect of these factors on cleaning was compared as in section 3.1. Change in whiteness Index value was computed.

### 3.3.1 ACOUSTIC PARAMETERS

Acoustic parameters included frequency and power. Cavitational intensity is an integral function of the frequency and amplitude of a radiating wave (a function of power) and this has to be sufficient to break the bond between the contaminant and substrate (Azar, 2009).

**3.3.1.1 EFFECT OF FREQUENCY**

There is no uniform frequency recommended for cleaning in technical literature as optimum frequency would depend on the size of the contaminant, nature of the substrate, cleaning medium and cleanness requirement. Frequency therefore had to be studied and customized keeping these factors in mind. Work was carried out at six frequencies viz. 25, 40, 58, 132, 192 kHz and a dual frequency of 58 + 192 kHz at the premises of Crest Ultrasonic India, Functional Industrial Estate, Patparganj, Delhi on four different ultrasonic machines. Experiments were carried out at the previously optimized conditions of time, temperature and concentration with commercial as well as standard reference detergent, for unmasked clarity (as presence of oxidizing agents, FBA's and other performance enhancing chemicals in commercial detergent can possibly obliterate the findings). For comparison of cleaning efficiency, Variation analysis ANOVA for repeated measurements was done to test for effect of different frequencies to see if change in frequency significantly affects cleaning efficiency. This was followed by Tukey Post Hoc Test for multiple comparisons to identify similar/ dissimilar frequencies. Frequency which gave maximum cleaning was identified and further comparison of this frequency with all other frequencies using Students' unpaired t- test for equality of means was done. These tests helped to isolate frequencies which gave maximum and comparable cleaning. Final frequency for fabrication of garment cleaning prototype was decided based on this analysis.

**3.3.1.2 EFFECT OF POWER**

The amplitude of the radiating wave is directly proportional to electrical energy (power) that is applied to the transducer. For cavitation to be produced in a liquid medium, the amplitude of the radiating wave must have a certain minimum value, no cavitation can occur below this threshold value. To see the effect of power on cleaning efficacy experiments were carried out with standard soiled samples on a 40 kHz, 300 W ultrasonic machine with adjustable power. Work was carried out on Crest Ultrasonic machine, model no. - CP2600D, with tank capacity of 26l and a digital interface. The output power level was varied between 10%-100% of the nominal output (30-300 watt) at 10% / 30 kHz gap. Cleaning efficiency at various power levels was studied and compared with the theoretical formula for power calculation which is 50- 100 watt per US gallon of cleaning liquid or 2.8-3.6 watt per square inch of transducer radiating surface (these values are applicable only to piezo- electric transducers) t2hotline@aec.apgea.army.mil.

Variation analysis ANOVA was done to see if variation in power effectuates corresponding variation in cleaning. This was followed by Tukey (HSD) post hoc test for multiple comparisons to determine the significant differences between group means in an analysis of variance setting. This was followed by t- test. The statistical analyses helped to identify suitable power range for effective cleaning with ultrasonic technique.

### 3.3.2 MACHINE PARAMETERS

To study how the machine parameters affect cavitational intensity, amount of gas present in the cleaning medium and number of operating transducers in the ultrasonic machine were varied and its consequent effect on cleaning was examined statistically.

#### 3.3.2.1 EFFECT OF DEGASSING THE CLEANING MEDIUM

Degassing is the removal of unwanted dissolved gas from the cleaning liquid, as they otherwise serve as 'shock absorbers' and can reduce cleaning efficiency. For studying the effect of degassing in this study a combination of high temperature and switching on the degassing mode of the ultrasonic machine before entering the samples to expel gas was attempted. Samples were tested at 40 kHz, 300 watt ultrasonic machine with a degas mode (courtesy: Crest Ultrasonic India). The machine was operated at half wave modulation for 10 minutes (as recommended in the service manual of the machine) for degassing with detergent solution. In half wave, the generator cuts the pulse to the transducer every other half of the wave which allows the gas to escape quickly. Comparison of samples exposed to ultrasonic energy for 1 minute in degassed and non–degassed medium was done using students t - test for independent means.

#### 3.3.2.2 EFFECT OF NUMBER OF OPERATING TRANSDUCERS

The ultrasonic cleaning unit II fabricated at NITRA, used for this part of the study had six piezo - ceramic transducers (section 3.1.2.3). The number of transducers in a system depends on the size of the tank, and is calculated accordingly. To see the effect of number of operational transducers on cleaning, work was carried out in the ultrasonic cleaning unit II where if only circuit 1 was operated, 3 transducers would be operational where as when both circuit 1and 2 (31 &39 kHz) are switched on, all 6 transducers become operational. For the purpose of comparison data was also generated on the ultrasonic cleaning unit I; machine which had single transducer (33 kHz). Variation analysis confirmed the effect of variation in number of transducers on cleaning as highly significant for both detergents. Further, Tukey post hoc test for ANOVA was done followed by t- test between all groups.

### 3.3.3 PROCESS PARAMETERS

Process parameters such as effect of distance between the transducers and substrate and fabric arrangement were studied.

#### 3.3.3.1 EFFECT OF DISTANCE BETWEEN TRANSDUCER AND SUBSTRATE

According to the literature, the distance of $\lambda/2$ and its multiples from the transducer is the zone for maximum cavitational intensity (Moholkar, 2002). Wavelength of sound is affected by various factors and is therefore not easy to predict. To find the optimum distance/s from transducer where the substrate should be placed so that it corresponds to the area of maximum cavitational intensity, samples were soiled and tested at various heights in the ultrasonic cleaning unit II, where transducers were attached to the base of the tank. The distance of the sample from transducer was varied with the help of the movable frame such that testing was done at eight different positions. The first position was 2.5 cm away from the base, with a gap of 1cm between each subsequent position; the last position being 9.5 cm away from the base. Wavelength of sound wave was considered while planning heights at which testing was done such that some of these corresponded to $\lambda/2$ and its multiples and some to $\lambda/4$. Cleaning at various positions was compared as higher cavitational intensity would result in better cleaning. One way analysis of variance ANOVA revealed if variation in distance of substrate from transducer significantly affects the resultant cleaning. To identify the positions where comparable and maximum cleaning occurred Tukey test was done, followed by independent Student’s t- test for group means for validation.

### 3.3.3.2 EFFECT OF FABRIC ARRANGEMENT

To find suitable fabric arrangement for optimum utilization of ultrasonic energy placement of fabric in the cleaning tank as well as fabric thickness was varied and studied.

#### 3.3.3.2.1 EFFECT OF FABRIC THICKNESS

Due to the reticulate nature of the textile material, it was hypothesized that behavior of sound waves will be different in a bi-porous material than in solid substances. For better understanding of effect of substrate thickness on cavitational intensity experiments were carried out on single/multiple layer of fabric. Collars with interlining were stitched to represent multilayered fabric and were soiled. 16 such assemblies were constructed half of which were exposed to ultrasonic energy in free floating form in the tank, while the other half were constrained during treatment. Treated samples were compared for the degree of cleaning.

#### 3.3.3.2.2 FABRIC PLACEMENT IN TANK

Experiments were performed to see the effect on cleaning of fabric placement, while sample is in free flowing form in the ultrasonic tank vis-à-vis when it was constrained in a metal frame and then immersed in the ultrasonic tank. It was postulated that constrained fabrics might help ultrasonic energy to clean more effectively as the metallic backing would prevent loss of energy, sound waves would be reflected upon hitting the metal backing rather than getting transmitted through the free flowing fabric. As higher cavitational intensity would translate into better cleaning; percentage change in whiteness index values of samples was compared for cleaning efficiency.

To find the effect of fabric thickness and fabric placement on cleaning efficiency, Student's t-Test for independent samples was applied for comparison of means of single and multilayered fabric in both positions i.e. when it was free floating in the tank vis-à-vis when it is constrained. All four groups were compared to each other by administering t- test for both detergent systems. p values revealed the suitable fabric thickness and placement such that optimal cleaning results would be achieved.

Various parameters concerning the acoustics, machine operations and wash process that can influence system efficiency were studied prior to fabrication of the customized equipment for washing of highly soiled apparel. This helped in integrating operating considerations with structural requirements which facilitated design and development of garment cleaning prototype.

## 3.4 DESIGN AND DEVELOPMENT OF ULTRASONIC GARMENT CLEANING PROTOTYPE

Findings of the experiments in section 3.3 revealed various parameters that are responsible for the resultant cavitation intensity in the cleaning medium. These factors on being suitably modified would result in intensification of cavitational intensity, which in turn would lead to better cleaning. New ultrasonic cleaning unit was designed and fabricated taking into account the outcome of previously conducted experiments which helped in integrating operating parameters as well as other structural requirements, at NITRA Ghaziabad in collaboration with Crest Ultrasonics India Pvt. Ltd. After fabrication the operating parameters and wash process conditions for the prototype were reviewed and optimized so as to maximize system efficacy. Finally, to assess the technical and economical viability of this newly developed washing prototype in commercial set-up, field trials were conducted.

### 3.4.1 FABRICATION OF ULTRASONIC GARMENT CLEANING PROTOTYPE

The following steps were followed in fabrication of Ultrasonic Garment Cleaning Prototype.

#### 3.4.1.1 OPERATING CONSIDERATIONS

Acoustic parameters studied in the previous section were instrumental in establishing the critical operating parameters of the machine: Frequency and Power

**FREQUENCY**

Regression equation was derived and plotted based on the findings of experimental work done on various ultrasonic machines of different frequencies (section 3.3.1.1). The raw score formula for regression of Y on X used is as follows:

$$Y' = \left(r\frac{S_y}{S_x}\right)X - \left(r\frac{S_y}{S_x}\right)\overline{X} + \overline{Y}$$

where
Y' is the predicted raw score in Y
$S_x$ and $S_y$ are the two standard deviations
$\overline{X}$ and $\overline{Y}$ are the two means
r is the correlation coefficient between X and Y(Minium *et al*., 2008).

On careful examination of cleaning results obtained, it was observed that increase in frequency did not result in significant improvement in cleaning although it would significantly increase the cost, higher frequency cleaning systems being many times more expensive.

With this background, 40 kHz frequency, due to its technical and economical viability, was considered optimum for ultrasonic prototype designed for cleaning of highly soiled apparel.

Provision to introduce sweep frequency into the system at constant intervals was conceptualized; as this would improve homogeneity of results by distributing cavitational energy more evenly.

**POWER**

A certain amount of energy is needed to achieve threshold of cavitation. Power can be calculated either in terms of watt density/area of face which is 5-7 watt/inch$^2$ or in terms of volume, which is 50-100watt/gallon (Mason, 1991). Power can also be calculated as per the following formula:

$$\frac{L\ (in) \times W\ (in) \times (H - 2'')}{231} \times 100 = Avg. Watts\ Power$$

(t2hotline@aec.amy.mil). Volumetric determination being more realistic was followed. Correspondingly regression equation based on results of effect of variation in power undertaken in section 3.3.1.2 was derived and plotted. As change in power significantly affects the cleaning efficiency of ultrasonic system; provision to vary power output with power intensity control switch was planned. It offered an option to vary power output from 10%-90% of its nominal value corresponding to 50W-500W. This facilitated study of effect of power on cleaning efficiency such that prototype could be operated at optimum power as per the substrate or contaminant or both. The power mentioned above is the electrical power consumed by generator from the mains and not the acoustical power emitted in the liquid.

**3.4.1.2 STRUCTURAL REQUIREMENTS**

To get an operational ultrasonic cleaning prototype the logistics of providing the previously identified machine parameters such as correct frequency, power, provision for degassing the cleaning medium etc. was accomplished by identifying and fulfilling the structural requirements of the prototype. These are enumerated as follows:

**TYPE OF TRANSDUCERS**

Ultrasonic energy of desired frequency is transmitted to liquid by means of transducers that convert electrical energy to acoustic energy. Selection of transducer was done after finalizing the frequency. There are two types of ultrasonic transducers available: piezoelectric transducers and magnetostrictive transducers. A detailed survey of the available options and a comparison of their relative merits was done. This helped in finalizing the category i.e. piezoelectric transducer as well as the type of transducer i.e. ***Immersible Transducer*** as the most suitable option especially because of its flexibility of use (FIGURE 3.5).

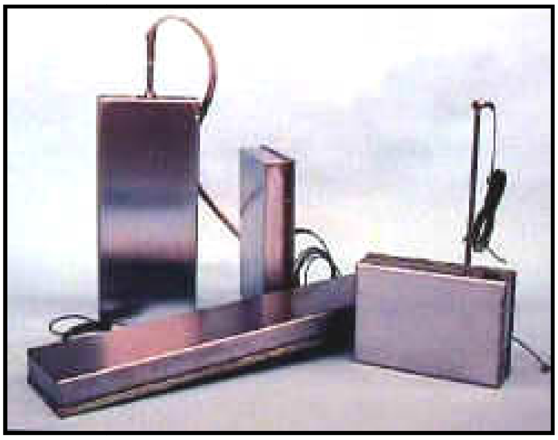


**FIGURE 3.5: DIFFERENT SHAPES OF IMMERSIBLE TRANSDUCERS**
(Source: Crest Ultrasonic Product Catalog)

**ULTRASONIC GENERATOR**

An ultrasonic generator energizes the transducer. The generator transforms the electrical energy from the power source into a suitable form for efficiently energizing the transducers at the desired frequencies. The generators are custom designed to power a specific number of transducers. Each transducer requires a minimum amount of voltage to activate, usually about ¾ of the maximum voltage of the transducer.

A generator with controls for varying the amount of power to the transducers, (Power Intensity) and a built in frequency sweep that will vary the frequency sweep rate (sweep frequency rate control) over the operation range of the transducer was conceptualized with a control that would automatically turns the signal on an off very rapidly to help degas the cleaning solution.

Most generators are designed in modules that will operate a specific amount of transducers. The most common are 250, 500, 750, and 1000W sizes, simply adding additional generator modules to the system can operate transducer stacks of any size. Based on the calculation of optimum power requirement for this particular cleaning gadget, generator power and type was finalized.

**PROVISION FOR DEGASSING THE CLEANING MEDIUM**

Dissolved gases must be driven out of solution for an ultrasonic cleaner to work properly, any dissolved gas in the cleaning fluid will migrate to the area of lowest pressure (the vacuum cavity) preventing the violent collapse of the cavity and thereby reducing its cleaning power. Provision to remove this gas by modulation of ultrasonic wave was planned.

**THERMOSTATICALLY CONTROLLED HEATED TANK**

The choice of material and the manner in which it is welded also have an effect on the performance of the final ultrasonic tank. For present work, heavy duty steel tank with smooth edges and corners, of appropriate size as per the size of the transducer was selected. The curved inside edges and smooth ground was chosen, so as to reduce particle retention in the tank when emptied after cleaning operation.

**WORK BASKETS AND FIXTURES**

Work basket and other fixtures were designed so that they have as little mass as possible. Designs with open construction to facilitate free passage of both sound waves and cleaning fluid were planned. Stainless steel which is a hard sound reflecting material was selected, as recommended in literature, as softer materials absorb ultrasonic energy.

Illustrated below is a concept diagram for Ultrasonic garment cleaning prototype (FIGURE 3.6).

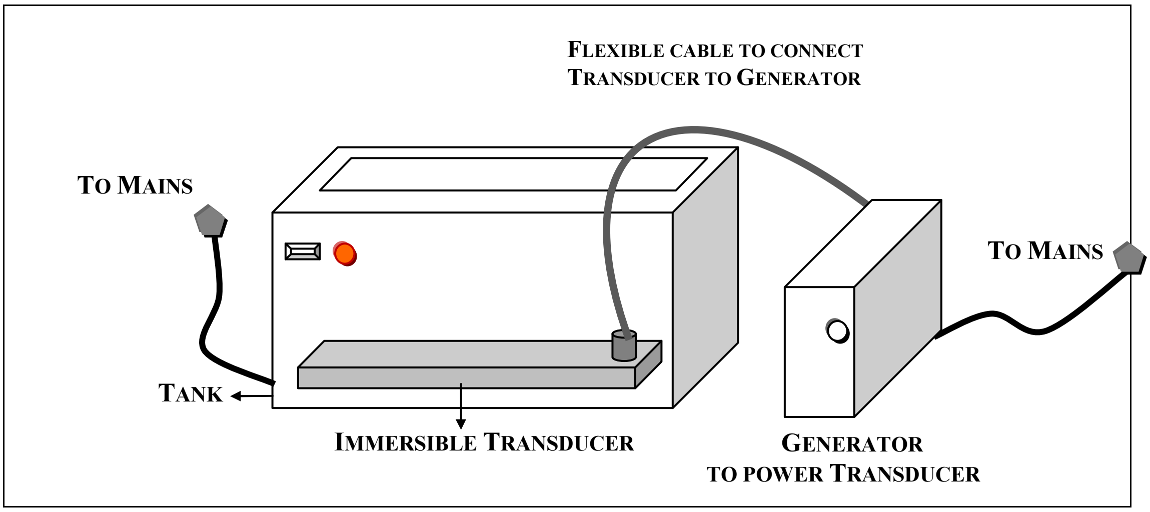



**FIGURE 3.6: BLOCK DIAGRAM FOR ULTRASONIC GARMENT CLEANING PROTOTYPE**

### 3.4.2 EVALUATION OF ULTRASONIC GARMENT CLEANING PROTOTYPE

Review and optimization of cleaning parameters for ultrasonic garment cleaning prototype was done followed by evaluation of its cleaning efficiency under these conditions.

Niemczewski (2003) while proposing a test procedure for ultrasonic cleaners stated that cavitation and radiation pressure depend on frequency of operation of cleaner as well as on its electrical power, and are characteristic for any given cleaner considering differences in tuning of the generator to the resonant frequency of the transducer. Moreover, they are different for different cleaning media. That is why it is not possible to have a unified method of assessment of operation of ultrasonic cleaners.

With this background, review of some of the previously optimized parameters was done to suggest the optimum cleaning conditions for this gadget. Once the system's cleaning parameters were reaffirmed, comparison of its cleaning efficiency with conventional method of washing as well as with the previous model, ultrasonic cleaning unit II (section 3.1.2.4) was undertaken. Fabric was desized, scoured and bleached (section 3.1.2.1), soiled samples were prepared (section 3.1.2.2) and their reflectance values and whiteness index readings were taken. Whiteness index reading (before and after treatment) were tabulated. Percentage change in whiteness index readings (before and after treatment) was used as a criterion for evaluating cleaning efficiency for the experiments. ANOVA, was used to detect differences in treatments across multiple test attempts for power, transducer position and distance from substrate, temperature, level of gas present in cleaning medium, level of soiling and presoak time. Following this Tukey post hoc test for multiple comparisons revealed the groups which were significantly different from one other. The relevant groups were further compared by administering student t- test for independent means so as to identify optimum operating and washing conditions for cleaning highly soiled apparel.

#### 3.4.2.1 POWER

While a certain minimum power is needed to cross the threshold barrier but an uninhibited increase would not enhance cavitation intensity and therefore the resultant cleaning. To find critical power range for optimum cleaning; the output power level was varied using power intensity control switch between 10%-100% of the nominal output (50-500 Watt) at 10% or 50 kHz gap. Level of cleaning achieved at various power levels was compared to isolate optimum range for power input to the system for cleaning highly soiled apparel.

#### 3.4.2.2 TRANSDUCER POSITION (EFFECT ON SPATIAL DISTRIBUTION OF ULTRASONIC ENERGY)

The number of transducers in a cleaning system is based on the size of the tank, bigger the tank more the number used. In a standard fabrication it is carefully calculated by the manufacture but in case of immersible transducer which can be placed in any tank bigger than its own size, it was important to see if the number of operational transducers and tank size complement each other and uniform energy is generated in the system to break the bond between contaminant and substrate for effective cleaning. For this a special fixture was designed which had no bottom and would fit perfectly on the immersible transducer. The grooved edge at the top facilitated the placement of sound insulating partitions (FIGURE 3.7). There were 12 transducers in all, in paired configuration in the immersible transducer. The engineering drawing sourced from the manufacturer gave exact location of the transducer in the immersible (Appendix VI). With the help of the drawing, a method for placement of sound proof separators was devised such that the number of operational transducers to which a sample is exposed in a designated zone could be varied from 1-12 (Appendix VII). In the present work sound proof separators were placed in such a manner that the area blocking as well as number of effective transducers to which the sample was exposed was controlled and varied from 1-12. This facilitated the study of spatial distribution of cavitation in the tank.

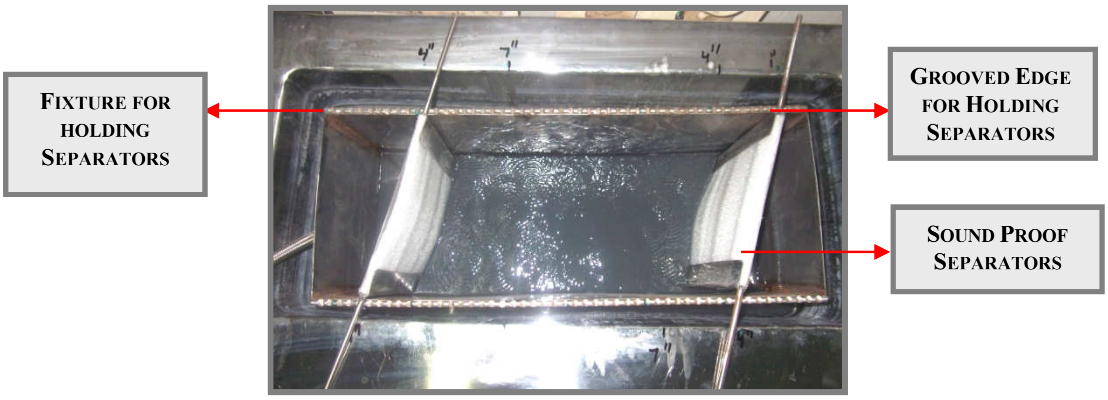



**FIGURE 3.7: ISOLATION FIXTURE AND SEPARATORS IN ULTRASONIC CLEANING TANK**

Whiteness index values before and after wash in each zone were tabulated, percentage change in whiteness index value achieved with varying number of operational transducers in each zone was statistically compared.

**3.4.2.3 EFFECT OF TRANSDUCER DISTANCE (FROM SUBSTRATE)**

The distance between sample and transducer attached to the base of the tank was altered to maintain various positions for test to identify the distance corresponding to maximum cavitational intensity. For the present work testing was done at nine positions with a gap of 2 cm between each subsequent position; the first position being 3.5 cm away from the immersible transducer placed at the bottom of the tank. As per the literature, wavelength (λ) for a 40 kHz ultrasonic system is 37.5mm in soft water. Wavelength is a function of many factors and varies with change in temperature, presence of detergent in the cleaning liquid which lowers surface tension, velocity of sound in the media as well as other factors i.e. why testing at various distances was done, while taking care that some of these correspond to λ/2 and its multiples, some to λ/4 and some to neither. Cleaning at various positions in the tank was statistically compared as higher cavitational intensity would result in better cleaning.

**3.4.2.4 EFFECT OF TEMPERATURE**

The factors involved in ultrasonic cleaning are not only cavitation, but also liquid streaming due to radiation pressure of the ultrasound, and chemical activity from substances dissolved in water such as alkali and detergent. The intensity of both these last agents increases with temperature while cavitation intensity decreases (Niemczweski, 1980).

Optimal temperature for a system therefore is a tradeoff between maximum cavitational intensity and radiation pressure. This is unique for each cleaning system depending on the constituents of the cleaning medium. Work was carried out at temperatures: 30, 40, 45, 50 and 60°C for identifying the optimum temperature conditions for cleaning heavily soiled apparel in the developed prototype.

**3.4.2.5 EFFECT OF DEGASSING**

Ultrasonic tank was degassed with the help of a toggle switch set at "lo position" for 10 minutes, which introduced ultrasonic waves at half modulation to the cleaning media. In "Half wave" modulation peak power is the same but average power is reduced by half. Whiteness index value before and after wash, with/without degassing of the cleaning medium, was noted. Percentage change in whiteness index values achieved was statistically compared by applying Students t–test for independent means.

#### 3.4.2.6 EFFECT OF DEGREE OF SOILING

The aim of the present work was to clean highly soiled apparel effectively, it was therefore important to outline the relationship between level of soiling and cleaning achieved with ultrasonic prototype. For this samples were soiled as per section 3.1.2.2 such that whiteness index of the soiled samples was varied from 30-75. To study the effect of degree of soiling on ultrasonic cleaning efficacy, whiteness index values (before and after wash) were noted. Pearson's correlation coefficient was computed between before and after wash whiteness index values of multiple samples. It is a measure of the strength of the linear relationship between two variables that is defined in terms of the (sample) covariance of the variables divided by their (sample) standard deviations (Minium *et al*., 2008). Further, the sample was divided into three categories based on their level of soiling: Heavily soiled (W.I. = 30-45); moderately soiled (W.I. = 45-60); lightly soiled (W.I. = 60-75). Correlation coefficient for these three groups was also computed and interpretations were derived based on r value.

#### 3.4.2.7 EFFECT OF PRESOAK TIME

Effect of presoak time on ultrasonic cleaning was studied at optimized conditions by varying it from 5-30 minutes. Whiteness index values before and after wash were noted, percentage change in whiteness Index after washing was used as a criterion for quantifying soil release. Variation analysis was done to confirm the effect of soaking time on cleaning efficiency. This was followed by Tukey post hoc test to perform a pair wise comparison of the means to see where the significant differences existed. This helped to identify time durations which gave comparable cleaning.

These experiments provided the optimum process conditions for machine operations so that the wash load is exposed to ultrasonic energy under maximum cavitational intensity conditions for effective cleaning.

### 3.4.3 EVALUATION OF CLEANING EFFICIENCY OF DEVELOPED PROTOYPE

After studying the various factors affecting ultrasonic cleaning, optimum cleaning conditions for the newly developed prototype were identified. To reaffirm its cleaning capability vis-à-vis conventional washing, highly soiled samples were washed using both methods. Comparison was also done with the ultrasonic unit II (section 3.1.2.3) to highlight improvement in cleaning performance of this prototype. Cleaning efficiency in terms of percentage soil removal was calculated as per IS: 5785 (Part IV) -2005

### 3.4.4 FIELD TRIALS OF THE DEVEVELOPED PROTOTYPE

After establishing the operational parameters and optimizing the wash process conditions for ultrasonic garment cleaning prototype, it was field tested at a commercial laundry unit. This was undertaken to establish the technical and economical feasibility of operating the prototype in commercial set-up. Its efficacy as a pretreatment to replace brushing of highly soiled garments and compatibility with industrial cleaning agents was also tested.

#### 3.4.4.1 LOCATION

Field trials were conducted at premises of Wardrobe, cleaning solutions, a brand of Diamond Fabcare Pvt. Ltd., Noida set up in collaboration with Brown Gouge, Australia and member of Dry Cleaning and Laundry Institute, USA. At the time of the study this was the leading laundry unit in Delhi NCR, with 63 outlets and handled over 8 tons of laundry/day. Comprehensive facilities and designated work areas for drycleaning, machine and hand washing of wash loads made this unit conducive for field testing.

#### 3.4.4.2 SAMPLE

The selected unit washed soiled articles received from households and from institutions, primarily hospitality sectors. Purposive sampling was followed; heavily soiled uniforms and delicate apparel items were selected for trial. 50 shirts, which are normally brushed in the hand washing section of the unit followed by washing in the industrial washing machine, were selected for trial in the ultrasonic machine for pretreatment. 50 delicate apparel comprising of embellished articles with embroidery, bead work etc on delicate fabrics like chiffons, georgettes, crêpe and net were selected and washed in ultrasonic garment cleaning prototype. The results were compared with normal washing procedures employed by the unit.

**3.4.4.3 TRIALS**

Whiteness index readings for white samples and digital photographs of colored samples were taken for reference. Same coding as followed by the unit for garment ID was followed. Test garments were pretreated in ultrasonic machine for 1 minute at ambient temperature to simulate washing conditions during brushing of soiled areas of a garment. These were subsequently washed along with the regular load in the industrial washing machine; Milnor washer extractor, 135lbs. rated capacity, wash load normally put is 85% of this capacity for optimal cleaning. For purpose of maintaining parity, type and concentration (g/l) of commercial detergent, as is used in the unit was added to the ultrasonic tank.

**3.4.4.4 EVALUATION**

Cleaning was evaluated both visually and instrumentally. For visual evaluation a 5 point rating scale was developed. On this continuum, a rating of 5 meant highly satisfactory cleaning results while 1 meant highly dissatisfactory cleaning. The evaluation was done by the researcher along with 3 senior supervisors from the unit to avoid bias. For white articles both visual and instrumental analysis was done while for colored garments only visual rating was done.

Instrumental analysis was done using Data Colorlab portable spectrophotometer. Whiteness index was measured as per Hunter's lab scale using computer color matching system. The illuminant used was $D_{65}$ with $10^{o}$ observer. The whiteness index of soiled and washed samples was measured taking necessary precautions to ensure the area measured after treatment was same as before by careful placement of the markers as there was no provision for LAV (large area volume) aperture setting. A mean of three reading was taken for each sample.

**3.4.4.5 ANALYSIS**

Difference in Whiteness index readings (before and after treatment) was used as a criterion for evaluating cleaning efficiency for white articles. For colored articles, visual rating scale data was compiled. Mean value of ratings as given by 4 evaluators was recorded and efficiency of ultrasonic machine analyzed.

**3.4.4.6 ECONOMIC BENEFIT ANALYSIS**

To quantify the economic benefits of ultrasonic cleaning, data regarding current practice followed in the unit was collected and collated. Details regarding resources employed (labor and energy) in the current practice and their respective cost to the company was collected, correspondingly cost of operating the ultrasonic machine in this set-up was also investigated. This facilitated the computation of cost comparison of operating the ultrasonic prototype vis-à-vis present practice of manually brushing the highly soiled areas.

Machine settings and wash process conditions for optimum cleaning effect were identified. Cleaning efficacy of the prototype, under controlled conditions in the laboratory as well as in the commercial set up, was established. Computation of cost of operation of this prototype in commercial settings was undertaken.

## 3.5 ASSESMENT OF EFFICACY OF ULTRASONIC CLEANING PROTOTYPE ON VARIOUS SUBSTRATES, SOILS AND STAINS

Ultrasonic cleaning was conducted and evaluated for its efficacy using instrumental analysis (section 3.1.2.4) on various parameters.

### 3.5.1 SUBSTRATES

Ultrasonic cleaning efficacy was tested on substrates on which conventional methods of mechanical action like agitation, scrubbing, pounding, brushing etc. are not desirable. For this, different fabrics (TABLE 3.5) were soiled as per IS: 5785(Part IV)-2005. After presoaking fabrics in detergent solution for optimized time they were exposed to ultrasonic treatment in the new ultrasonic garment cleaning prototype. In addition, to simulate hand wash, samples were washed as per ISO: 6330:2000(E) Simulated hand wash procedure as outlined in Table1-Washing procedure for horizontal rotating drum machine –Type A[a] ( Detailed table in Appendix VIII). Samples were washed in IFB, fully automatic; front loading horizontal drum type; 6.5 Kg capacity washing machine at 40± 3°C with 66±1g of detergent added. Both standard reference, as well as neutral commercial detergent (*Ezee*) was used for experiment. Reflectance values of unsoiled, soiled and after washing for both the wash methods was measured and recorded. Level of cleaning achieved (reflectance value after wash) with both methods was compared by applying t- test for independent means. For printed and lace fabric visual evaluation for comparison with simulated hand wash was done.

**TABLE 3.5: DETAILS OF FABRICS STUDIED**

| Fabric | Code | Fabric weight (G.S.M.) | Yarn Count | | Thread Count | Weave | Additional Information- Finish/color/ print |
|---|---|---|---|---|---|---|---|
| | | | Warp | Weft | | | |
| Cotton | $C_1$ | 66 | $67^s$ | $69^s$ | 88x88 | Plain | White |
| | $C_2$ | 123 | $40^s$ | $40^s$ | 92x88 | Plain | White |
| | $C_3$ | 170 | $21^s$ | $19^s$ | 60x56 | Plain | White |
| | $C_P$ | 123 | $40^s$ | $40^s$ | 92x88 | Plain | Pigment printed |
| Silk | $S_1$ | 20 | $19D/282^s$ | $21D/ 249^s$ | 152x104 | Plain | Light Wt. |
| | $S_2$ | 44 | $40D/131^s$ | $46D/ 115^s$ | 121x100 | Plain | Medium Wt. |
| | $S_3$. | 54 | $41D/128^s$ | $56D/ 99^s$ | 188x112 | Plain | Heavy Wt. |
| | $S_P$. | 44 | $40D/131^s$ | $46D/ 115^s$ | 121x100 | Plain | Acid Printed |
| | $S_C$ | 44 | $40D/131^s$ | $46D/ 115^s$ | 121x100 | Plain | Dyed |
| Silk Crêpe | $SCr_1$ | 48 | 2/20/22D | 3/20/22 D | 128x100 | Plain | Wp Tpi – 55Z<br>Wf Tpi – 50S |
| | $SCr_2$ | 82 | 2/50D | 2/50D | 132x96 | Plain | Wp Tpi – 50Z<br>Wf Tpi – 45S |
| Rayon | $R_1$ | 168 | $36^s$ | $39^s$ | 138x86 | 2/1 Twill | Textured yarn |
| | $R_2$ | 216 | $27^s$ | $31^s$ | 96x80 | Plain | Textured yarn |
| Chiffon | $Ch_1$ | 36 | $46^s$ | $48^s$ | 101x 90 | Plain | Wp Tpi – 55Z<br>Wf Tpi – 45Z |
| Nylon | $Ny_1$ | - | - | - | - | Lace | |

### 3.5.2 SOILS

Various studies have been done to investigate the nature of soil present on the soiled garments. **Three types of soils** which fulfilled the criterion of everyday occurrence on heavily soiled garments were attempted. As detergency mechanism for oily (liquid) soils and particulate soils are different (Kissa,1981) Standard soil recipe as per IS: 5785(Part IV)-2005 which has carbon black particles, mineral oil and lanolin (fat) in its recipe (particulate as well as oily component) was applied under standardized conditions. Also dry particulate soil (Dirt) was attempted. Besides the nature of the soil the soiling pattern of naturally soiled fabrics is different; distribution of natural soils on fibers is different than in laboratory prepared samples (Webb and Obendorf, 1987a). For this reason **naturally soiled samples of collars** were also tested.

100% grey cotton (plain woven) after desizing, scouring and bleaching was soiled with various soils and exposed to ultrasonic energy/automated scrubbing followed by machine wash (section3.2.2.2). For comparison control samples which were only machine washed after soaking in detergent solution and not subjected to any pretreatment were also tested. Three types of soils applied on the fabric were:

**Standard Soil Recipe**

As per IS: 5785(Part IV)-2005. Method of preparation and application of soil as per section 3.1.2.2

**Natural Dry Particulate Soil** (Dirt)

This is the most prevalent and apparent ordinary dirt found in the surroundings like streets, backyard, garden, athletic fields, etc. This ordinary dirt is easily visible on the garment but difficult to remove and generally requires additional mechanical agitation in form of brushing, scrubbing, rubbing, etc. Inamorato *et al*. (1975) developed test method utilizing natural dirt for evaluation of detergents. They studied soils from 9 different regions, but no relation between soil removal and nature of dirt was observed, similar ratings were obtained for various detergent products with different soils. In the present work dirt from Delhi region was used. This dirt was air dried to constant weight and sieved through a 200 size mesh screen to remove large particles. This was applied on to the pre-treated fabric cut into strips of size 30 X 7.5 cm, using wet abrasion scrub tester (Section 3.1.3.4.1) with some modifications. A 1 Kg weight on the top of the machine was placed and test fabric was lengthened by adding extra strips of fabric on both sides to facilitate securing on to the machine. A pre-weighed amount of dirt (1g) was sprinkled on to the fabric, slightly moistened using the fluid pump of the machine. The brush was then lowered on to the fabric surface and machine switched on for half a minute. It made thirty back and forth motions in half minute and dirt was applied (PLATE 3.1 C,D).

**Naturally Soiled Woven Shirt Collars**

Although various studies enumerate the composition of human sebum and attempts to duplicate it have been made, but natural soiling pattern cannot be suitably duplicated. Heavily soiled areas like collars and cuffs are almost never uniformly soiled. Therefore, to duplicate natural soiling closely, collars with inter-lining were stitched and given to 12 subjects to wear around the neck, sometimes on top of the existing collar, as the case may be, and held in place with the help of paper clips. The soiled collars returned after a standard day's wear were used for the study. This was repeated for the 3 days to collect the requisite number (PLATE 3.1 A,B) .

Whiteness index readings after pretreatment and subsequent machine wash for various soils and various washing methods was tabulated, graphically represented and statistically compared. Variation analysis was done to see if the effect of washing method had significant effect on soil removal for all three types of soils. All three washing methods were further compared with each other using t- test for all three soils. This helped to strengthen the proposition of ultrasonication as an alternative to conventional washing method.

### 3.5.3 STAINS

To test the efficacy of ultrasonic cleaning on various stains standard soiled strips as prescribed in standard method-IS:14155:1998 'Domestic Electric Clothes Washing Machines for Household Use-Specifications' were used. The referred standard for this is IEC: 604556:2001(International Electro Technical Commission).

**Specimen**

Square specimens measuring 150±20 mm soiled with four different standard soils in the following order: Carbon black + mineral oil, pig's blood, chocolate milk and red wine were used. The strip is formed by joining specimens with four kinds of soil. An unsoiled sample of same fabric as soiled cloth is attached on top of the strip as blank control.

For the present work, in preparation of soiled strips, pig's blood soiling was replaced with Indian curry considering its practical aspect and day to day usability under Indian conditions and Indian red wine 'Riviera' in place of Alicant's red wine was used. FIGURE 3.8 shows schematics of a soiled strip.


**FIGURE 3.8: SCHEMATICS OF A SOILED STRIP**

**TABLE 3.6: PROPOSED REFLECTANCE STANDARDS**

| S. No. | Type of Soiling | % R values to be maintained |
|---|---|---|
| 1. | Carbon Soiling | 25 ± 5 |
| 2 | Indian Curry | 25 ± 5 |
| 3 | Red Wine | 40 ± 5 |
| 4 | Cocoa &Milk | 19 ± 5 |

**Number of Strips**

The number of strips used for washing test was proportional to the size of the wash load. As recommended 6 strips for washing machines with load capacity greater than 5.4 Kg were used.

**Measurements**

Reflectance measurements were taken before and after washing, two on each side of each specimen thus giving a total of 16 measurements per strip. Each measurement was taken after turning the sample through 90° to provide an average for each position.

**Wash Load**

Standard test load of textile material equal to the rated capacity of the washing machine was added along with the strips for washing. The composition and dimensions of this load were as per section 5.2.6 (Table2) of IS: 14155:1994.

**Detergent Concentration and Temperature**

60 gm of commercial detergent in IFB washing machine as prescribed in the method and proportionate amount of detergent in 30 l capacity ultrasonic washing equipment was added. Prescribed water temperature of 48±2°C was followed for ultrasonic and machine washing.

**Washing Cycle**

Five complete washing cycles after loading in accordance with the manufacturer's instructions for the longest programmed cycle were carried out as per the IS:14155 method. Samples were washed along with the prescribed wash load as per the machine capacity. After each washing cycle samples were withdrawn, dried and ironed between two pieces of fabric to avoid '*Shine*' and reflectance measurements were taken.

Alternatively, soiled strips were washed in ultrasonic machine such that the agitation time in washing machine corresponded to the duration for which ultrasonic machine was operated. This was followed by rinsing in the washing machine.
The method prescribes, in absence of manufacturer's instructions, for rotating drum type machinewas washing time = Heating up time + 10 minutes.

**Evaluation**

Reflectance values measured before soiling, after soiling and after washing were used as evaluation criterion. Comparison of absolute values obtained with machine and ultrasonic washing for various soils was done. These values were tabulated and expressed graphically for each type of stain separately. Besides instrumental analysis, visual examination of samples was also done by comparing digital photographs of test strips before and after machine/ ultrasonic wash.
Different kinds of soiling in this method enabled to measure following characteristics: Scouring effect due to mechanical and thermal action, specimen used being soiled with carbon black and mineral oil; removal of Protein and Organic pigments, specimen used being soiled with chocolate milk and Indian curry; and Bleaching effect was seen with specimen soiled with red wine.
Efficacy of ultrasonic washing technique in cleaning delicate materials was established. Its versatility in cleaning various types of soils and stains that can possibly be there on apparel was affirmed.