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I am submitting herewith a thesis written by Kathy Rhea Shelton entitled "Factors Affecting the Soil Removal Properties of Detergent Systems Containing Hydroxyethyl Cellulose." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Textiles and Clothing.

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FACTORS AFFECTING THE SOIL REMOVAL PROPERTIES OF DETERGENT SYSTEMS CONTAINING HYDROXYETHYL CELLULOSE

A Thesis

Presented for the

Master of Science

Degree

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Kathy Rhea Shelton

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In Memory of John H. Shelton, Sr.

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ABSTRACT

The objective of Phase I of this research was to evaluate low phosphate detergent formaulation containing hydroxyethyl cullulose as an antiredeposition agent, using varying surfactant combinations and pH levels. Phase II was involved with evaluating selected anionic surfactant, nonionic surfactant, and phosphate combinations.

The fabrics used were 100 percent cotton with a wash/wear finish and 65/35 polyester/cotton with a durable press finish. The fabrics were presoiled.

Soil removal experiments measured the ability of each detergent formulation to remove the oil bound carbon soil from the substrate. Soil redeposition experiments measured the ability of each detergent formulation to keep the soil suspended after it had been removed. Degree of soil removal and soil redeposition was determined by reflectance readings taken before and after washing on the soiled and unsoiled portions of each fabric swatch.

Statistical analysis was based on the analysis of variance using the percent soil removal and percent soil redeposition calculated from the reflectance data.

There were fifteen detergents formulated for Phase I of this research. Of these formulations the anionic-nonionic surfactant combination found to be superior was sodium p-triadecylbenzenesulfonate (anionic) and ethoxylated fatty alcohol (nonionic). Thirty-six detergents were formulated for Phase II. The most effective detergent formulation was

found to be 12 percent anionic surfactant, 10 percent nonionic surfactant, and 16 to 20 percent phosphate.

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CHAPTER I

INTRODUCTION

For several years federal and private interest in the problem of cultural or accelerated eutrophication of the nation's water supplies has increased as a result of the increasing severity of the problem. Eutrophication is a natural process in which aquatic plants are able to overproduce by utilizing an abundant supply of nutrients. As these plants die, they utilize much of the oxygen in the water, denying other life forms their required oxygen (10). Cultural or accelerated eutrophication results when man allows waste materials to run into the waterways (1). This waste contains many nutrients which increase eutrophication, one of these is phosphorus.

Phosphorus is not thought to be the only cause of the overfertilization, but is considered to be the most controlable at the present. Phosphorus enters the water ways by a variety of sources, such as land run-offs, fertilizer, decaying animals, human wastes , and detergents. At least 25 percent of this phosphorus is estimated to come from laundry and dish detergents (10). For that reason even a 50 percent reduction of phosphorus in detergents would bring about a substantial reduction in the percentage found in the water. As a result, recent legislation has been aimed at trying to control this ecological imbalance by placing restrictions on the amount of phosphorus which can be included in detergents.

Detergents marketed before this legislation were high in sodium tripolyphosphate content, as phosphate is one of the most effective builders functioning as a water softener and thus assisting soil removal. Phosphates assist in this high level of soil removal and suspension by having the following characteristics:

1. The power of the softening water by sequestering the metal ions (calcium and magnesium) which cause water hardeness;
2. The power of redissolving insoluble salts of these metals;
3. Synergistically aiding the detergents;
4. The power to emulsify and keep in suspension insoluble materials (4).

Reduction in the phosphate level has resulted in concurrent reduction in the soil removability factor in available detergents and in substantial consumer dissatisfaction with these laundry products. Considerable research has been initiated with the purpose of discovering new formulations which will combine low phosphate levels with excellent soil removal properties. One such formulation alternative is the use of superior antiredeposition agents which would prevent fabrics "picking up" soil while actually in the laundring process. In research done towards her Master's degree, Elizabeth Easter found that hydroxyethyl cellulose (HEC) is superior to carboxymethyl cellulose (CMC), the antiredeposition agent presently used in commercial detergents (10, 19). Cobble's research supports these findings by showing that a high (7.5 percent) content of HEC was effective with a moderate level (20 percent) of phosphate (6).

Another alternative in improving the effectiveness of detergents is increasing the alkalinity. A study involving this effect found that detergents with increasing levels of alkalinity and phosphate content correlated positively with increased soil removal (7). The study did not, however, deal with increased alkalinity and low phosphate levels.

Statement of the Problem

The problem is to find a more effective detergent formulation than those currently in use by combining low phosphate content with HEC as the antiredeposition agent. An effort will be made to determine the effect of surfactant composition and pH in relation to soil removal and redeposition.

Need for the Study

Despite the recent increase in research activity aimed at improving soil removability of detergents with low phosphate content, no solution has yet been found, and so the work must continue until the consumer is able to purchase a product which will work effectively, but not constitute a problem in terms of environmental pollution. Another problem in formulating a synthetic detergent is the hazards to the consumer. Some phosphate substitutes are caustic and are a serious hazard to children, some reduce the flame-retardant qualities of F-R treated fabrics, and some have adverse effects on the tubs of washing machines, causing them to corrode (9).

Because of the large number and complexity of variables which bear on detergent preformance, many studies may be required to determine precise

combinations of ingredients and conditions for achieving desired preformance. Very little research has involved the use of HEC. That research which has been done has related primarily to the effectiveness of HEC as an antiredeposition agent. There is a dearth of information about these properties as to how they are affected by varying pH levels.

Objectives

The broad objective of this study is to determine the factors which affect soil removal and soil suspension ability of low phosphate detergents which contain hydroxyethyl cellulose as the antiredeposition agent. Specific objectives of the study are:

1. To determine the preferred combination of anionic and nonionic surfactants for use in these detergents. (Phase I)
2. To determine the effectiveness of detergent formulations at three different pH levels—8, 9 and 10. (Phase I)
3. To determine the optimum levels of the anionic and nonionic surfactants in the preferred combination identified in the first phase of this research.

Assumptions

1. Oil bound carbon black is a valid soil for the evaluation of soil removal and soil redeposition.
2. Fabric reflectance measured by the Hunter Color Difference Meter is a valid measure of the degree of fabric soiling.
3. HEC is an effective antiredeposition agent.

Limitations

1. Only distilled water will be used.
2. Presoiled fabric, with oil-bound carbon soil, will be the only source of soil used.
3. The fabrics will be limited to two types, a 100 per cent cotton with wash/wear finish and a 65/35 polyester cotton with a durable press finish.
4. HEC will be the only antiredeposition agent used.
5. Only anionic and nonionic surfactants will be used.

Definitions

1. Antiredeposition agents-additives of synthetic detergents which help the surfactant in holding soil particles in suspension preventing them from settling back on fabrics (8).
2. Builders—components of detergents which aid the cleaning effectiveness of the surfactants by removing metal ions from the wash solution, maintaining the alkalinity of the solution, and preventing soil redeposition (8).
3. Detergency—process of removing soil from a solid material while immersed in a liquid medium, generally with the aid of a mechanical force and a chemical substance which reduces the attraction between the two (8).
4. Detergent—a chemically formulated product used in the cleaning process. Common ingredients are surfactants, builders, suds-controlling agents, antiredeposition agents, optical brighteners fabric softeners, and perfumes (8).

5. Soil—"matter out of place" (8) that results from aqueous or oily liquids, dry particulate matter, or a combination of one or more fluids with particulate matter (27).
6. Soil redeposition—precipitation of soil that has been removed from one substrate back onto that substrate or other substrates being laundered in the same medium (8).
7. Surfactant—term encompassing all classes of surface active elements including wetting agents, emulsifying agents, and detergents (8).

CHAPTER II

REVIEW OF LITERATURE

Pertinent literature was reviewed under the following topic headings: Detergency, Surfactants, Builder, Antiredeposition Agents, Soiling and Soil Removal, and Soil Redeposition.

Detergency

The process of laundering goes back in history prior to the discovery of soap. Without the aid of soap for soil removal, man had to rely on mechanical methods for cleaning. The most common were agitation with a stick, pounding with a stone, and friction by rubbing the soiled garments together. The use of soap was recorded as early as 70 A.D. It is assumed that the discovery of soap was accidental since it was not until 1741 that the constitution of the compound was understood. The work in early soap chemistry was very slow and it was not until 1811 that another major discovery was made. Chevreul found that soap formed insoluble salts with calcium and magnesium ions found in hard water; this reduced the amount of soap available for removal of soil. The need to overcome water hardness resulted in the first synthetic detergent in 1860 (18). It was not until the 1930's that the large scale production of synthetic detergents began (9).

The study of detergency is still ongoing. There is such diversity in the manners of soiling, in fabrics to be cleaned, and in the methods of cleaning that it would be impossible to determine an effective system without further research (8).

Detergency is any process of removing foreign matter from a desirable material by means of a cleaning agent (18). The functions of a detergent system in the cleaning process are as surface and interfacial tension depressants, solvents, dispersing agents, and stablilizing agents. In functioning as surface or interfacial tension depressants, detergents allow more complete penetration of water into and around the soil and the fabric. The solvents act with emulsifying agents to induce roll-up of oily soils. The hydrophobic tail of a surfactant molecule is absorbed into the oily soil, leaving the hydrophilic head in the water. The surfactant molecules keep attacking the oily soil and demanding more surface area until the soil rolls up and is lifted off the fabric (5). The dispersing agents aid in releasing solid particules from the fabrics. In order to keep the soils suspended in the aqueous laundering medium, stabilizing agents are used to increase the hydrophilicity of the soil (18, 17).

The pH level of synthetic detergents is determined by the nature of the ingredients used in their formulation. Most commercial detergents are manufactured to give solution pH values between 9 and 10. A higher pH level may result in more,effective cleaning but can also cause skin irritations (14). The acidity or alkalinity of a detergent can affect the cleansing ability of the system. Most detergents are alkaline to neutralize the natural acidity of most soils (22).

Ingredients that are common in built detergents but do not affect the cleansing process are optical brighteners, suds-controllers, anti-corrosion agents, antibacterial agents, and perfumes.

Optical brighteners have the ability of converting invisible ultra-violet light into visible light on the blue side of the color spectrum. The bluest cast complements any yellowishness present on the fabric, making it appear whiter (9).

Evaluation of the effectiveness of a laundry detergent involves the problems of measurement of the effectiveness of washing and the determintion of its effect on the washed material. The evaluation should be based on the performance of the product in four separate testing situations; laboratory testing, a practical laundry study, consumer testing, and sales testing. The laboratory testing is conducted in a completely controlled environment. The composition of the soils being removed is kept consistant but applied to different fabrics. The soils and fabrics used in the test should represent those found in home laundries. Clean fabric is washed with the soiled fabric in an instrument simulating a washing machine, such as a tergotometer or launderometer. The unsoiled fabric is used to obtain a soil redeposition measurement and the soiled fabric is used to measure soil removal. These two measurements are obtained by a reflectometer, in which a beam of light is reflected off the fabric and mechanically analyzed. The practical laundry involves evaluation of the laundry product under simulated domestic conditions. Standard washing machines and wash loads are used to determine the performance of the detergent in the home laundry. Some of the common detergent deficiencies that are observed in this test are; detergent dissolvability, excess sudsing, blue staining caused by optical brighteners, and soil removability in comparison with another detergent.

Consumer testing involves randomly selecting homes from the general public to test the detergent in their family wash. If a detergent is able to pass the first three steps, it is put out in the market to see if it can compete with other detergents on the basis of sales (2).

Surfactants

The purpose of surfactants is to increase the soil removability of detergents by breaking the attraction between the soil and the substrate, reducing the surface energy of the solvent. In order to do this the surfactant must be absorbed from the aqueous solution onto the soil; surfactants have the ability of being absorbed at interfaces of all types. The soil then breaks up into colloidal particles and is removed from the surface of the fabric by the aqueous solution (8).

Surfactant molecules have an oleophilic or hydrophobic group at one end and a hydrophilic group at the other end (8, 26). Each portion of the molucule acts independently. For a molecule at the solution-air interface, the hydrophilic end would have an attractive force down into the water. The hydropobic tail would be forced into the air because it is insoluble in water. As more molecules collect at the surface, the surface tension is reduced until the surface can admit no more molecules. The point at which the surface is completely filled with molecules is called the critical micelle concentration; then excess molecules are pushed below the surface into the solution. Because of their insolubility in water, the hydrocarbon tails of the excess molecules clump together to form micelles. The micelles attack the oil layer of the soil with the hydrocarbon tails, the hydrophilic heads are left in solution (12).

Surfactants may be classified as anionic, cationic, amphoteric, or nonionic. The classification is dependent upon the charge carried by the ion (3).

When an anionic surfactant ionizes in solution, the molecule dissociates into a negatively charged portion, which retains the surface activity and a positively charged counter ion. Many anionic surfactants can be effective in hard water even though they react with calcium and magnesium ions forming compounds. These compounds are soluble and do not interfere with detergency (7). Anionic surfactants are capable of stabilizing dispersions of particles with a negative charge. Particles of a positive charge absorb the surfactant molecules with the hydrocarbon chains in the water (8).

Nonionic surfactants are hydrophobic long chain hydrocarbons with a polyetheralcohol structure as the hydrophilic end. Ether linkages do not ionize and are weakly hydrophilic. The compound has no electrical charge but is effective by being soluble in water (22). Nonionics contain hydrophilic and hydrophobic portions which cause them to move in solution toward surfaces and interfaces. Since the nonionics do not ionize, they do not form salts and are effective in hard water (7).

Anionic surfactants were found to be the most effective of the four surfactants for soil removal on celluclosic fibers, while on a hydrophobic polymer the nonionic surfactants were found to be superior (11). A detergent system utilizing both surfactant types would be an effective cleaning agent for most fabrics.

Cationic surfactants dissociate in water and form positively charged surfactive ions. This class of surfactants is most often employed

as a fabric softener, and may also be used as a germicide and emulsifier (3).

Amphoteric surfactants contain both a positive and negative charge. The compound can neutralize itself at a given pH, resulting in nonionic characteristics. Amphoteric surfactants are not generally found in detergents (12).

Builders

Builders are components of detergents which "enable less detergent to do more deterging"; they are detergent extenders (18). Their main function is to increase the effectiveness of surfactants by removing the calcium and magnesium ions from the solution. These ions are extracted by means of sequestration or precipitation (8).

Another function of builders is to neutralize acidity in the soil and maintain the alkalinity of the solution. They also aid in preventing soil redeposition by electrolytically stabilizing emulsions of soil. This is done by increasing the negative zeta potentials of soils and fabric, causing an electrical repulsion between the soil and fabric (18). The zeta potential is an indicator of the electrical attraction or repulsion between particles and surfaces (8). Builders can also affect foam formation and stability (18).

Five main classifications of builders are phosphates, silicates, carbonates, oxygen-releasing materials and sundry builders (9). At the present, tripolyphosphate is the most commonly used builder.

As a result of recent legislation regarding environmental questions leading to reduced phosphate levels in commercial detergents, the cleaning

efficiency of the detergents has been reduced. One possibility to improve the soil removal properties of the low phosphate detergents is to increase the amount of the antiredeposition agent used in the formulation.

Antiredeposition Agents

Antiredeposition agents are ingredients in detergent formulas which help the surfactant suspend the soil particles, preventing them from redepositing back on the fabric. Carboxymethyl cellulose (CMC) is the most common antiredeposition additive found in detergents (8). CMC is effective as an antiredeposition agent because of its hydrophilic character, and the negative charge it carries is able to repulse negatively charged soil. The negative charges in the CMC are not arranged in the right order to aid in sequestering action, but they are able to keep the soil in suspension (8, 5). In high phosphate detergents, CMC is generally used at the 1.0 percent level.

Hydroxyethyl cellulose (HEC), a nonionic polymer, has been found to be a more effective antiredeposition agent than CMC on oily soils (19). Cobble's research shows that HEC ranks third in importance for prevention of soil deposition after nonionic surfactants and phosphate. This researcher recommended a 7.5 percent level of HEC to be incorporated in a low phosphate detergent (20 percent phosphate) (6).

Soiling and Soil Removal

Soiling and soil removal became a serious problem in 1964 when hydrophobic fibers were blended with cotton and then treated with a durable press finish (23). The absorption and retention of soils by these

fibers contributed to the graying, yellowing, and whiteness deterioration of the fabric (4).

There are three main categories of soils which affect the cleaniness of fabrics. The first is fluid soil. This class includes stains carried in aqueous or oily liquids (26). One example of this type would be sebum a secretion of the skin often found inside shirt collars and cuffs (28). The second category is dry particulate soils. This class includes soot, clays, metal oxides, and water-soluble materials (8). The third category is a combination of one or more fluid soils with particulate matter (26).

Soil retention can result from a variety of factors. Interfacial attractions such as Vander Waals and Coulomb forces bind soil to the fabric. Electrostatic attraction as a result of a durable press finish encourages soiling as well as making cleaning difficult. Soiling is also affected by the hydrophobic properties of a fiber; by its fineness, its physical surface irregularities, and by the twist of the yarn. The simplest soils to remove are those held by mechanical forces, such as coarse particles forced into the spaces between fibers or yarns (2, 23).

There are four primary steps in establishing a quantitative evaluation of soil release. There must be a uniform and reproducible method of soiling the fabric. The amount of soil retained on the fabric after the soiling process should be determined. A reproducible method of laundering the soiled cloth should be applied. The last step is determination of the amount of soil retained on the fabric (16).

Kissa found visual methods for the evaluation of soil removal to be inadequate because of colorless soils and the difference in analysts. Three mechanical methods were recommended because of their dependability.

One of these is the determination of the weight of the fabric before and after soiling, the difference being the weight of the soil. The fabric is weighed again after laundering and the data compared. Another common method of evaluation is by taking reflectance measurements of the soiled fabric before and after laundering (16). The reflectance values are converted into percent soil removal by the following equation (21).

$$\text{Soil Removal} = \frac{R_{sx} \quad R_{su}}{R_{tu} - R_{su}} \times 100$$

where R_{sx} = reflectance of soiled and washed sample

R_{su} = reflectance of soiled and unwashed sample

R_{tu} = reflectance of unsoiled and unwashed sample

The third method recommended was the use of radioactivity for the determination of tagged soil (16).

Soil Redeposition

Soil redeposition is the reprecipitation of soil that had been removed from the fabric and suspended in the wash bath, back onto the fabric. Redeposition results from a balance of opposing conditions in the detergent solution. If the fabric washed contains more soil than the detergent can keep suspended, it is redeposited on the fabric (18).

Soil redeposition is a result of interactions between types of soils, detergent formulations, types of fibers and fabric finishing agents, water hardness, and fabric construction. Redeposition causes a white fabric to become "tattle-tale gray" (2).

Two methods of evaluating soil redeposition are soil suspendability tests and deposition or redeposition tests. Soil suspendability tests measure the ability of a detergent system to suspend the soil and keep it from redepositing. A deposition test measures the suspending ability of a detergent by washing clean fabric in a dirty wash liquor. Reflectance readings are taken before and after the fabric has been washed. These readings are converted into percentages, giving a basis for comparison. When a redeposition test is used, soiled as well as unsoiled fabrics are washed in a soil-free detergent bath. Reflectance readings are taken on both fabrics before and after laundering. The readings are then converted into percentages (20).

CHAPTER III

PROCEDURE

Fabrics

Two types of presoiled fabrics were purchased from Testfabrics, Inc., P.O. Box 53, 200 Blackford Ave., Middlesex, N. J. 08846. The fabrics were 100 percent cotton broadcloth, bleached and mercerized with a wash/wear finish, and 65/35 polyester/cotton with a durable press finish.

The fabrics had been soiled by application of a soiling mixture with a printing roll, producing a uniform, solid, soiled band four inches wide. The cloth was then cut into nine inch rolls, allowing an unsoiled portion to remain on each side of the soiled portion. The soiling mixture was essentially a particulate carbon soil dispersed in an oily medium. The exact composition is given in Appendix I.

Fabric specimens for each experiment were 3-1/2 × 9 inch swatches of each fabric. Each fabric specimen was zig-zagged with cotton-covered polyester thread to prevent raveling. Each specimen was coded in the lower right hand corner of an unsoiled portion of fabric. The coding represented fabric, replication, detergent, and pH level (only in Phase I).

Materials Used to Formulate Detergents

A_1 - Cuponal ME (sodium lauryl sulfate)
E. I. du Pont de Nemours and Co.,
Wilmington, Delaware.

A_2 - Conoco C-650 (sodium p-tridecylbenzenesulfonate)

Conoco Chemicals; Continental Oil Co.

Ponca City, Oklahoma

N_1 - Triton X-100 (alkyl phenoxy polyethoxy ethanol)

Rohm and Haas

Philadelphia, Pennsylvania

N_2 - Alfonic 1412-60 (linear, primary alcohol)

Conoco Chemicals; Continental Oil Co.

Ponca City, Oklahoma

Sodium tripolyphosphate - Monsanto Company, St. Louis, Missouri.

Sodium sulfate - Sargent-Welch Scientific Co., Skokie, Illinois.

Hydroxyethyl cellulose - Hercules, Inc., Wilmington, Delaware.

The pH levels of the detergents used in Experiment Phase I were lowered to 8.0 or 9.0 with a 1 percent solution of hydrochloric acid or raised to 10.0 with a 1 percent solution of sodium carbonate. Tide detergent, commercially purchased, was used as a control in Experimental Phase I.

Formulation of Detergents

The detergent concentration in the laundering solution was approximately equal to that used in doing household laundry, 1.5 grams per liter (0.15 percent). The levels of the ingredients used are found in Table I and Table II. In Experimental Phase I (shown in Table I), the levels of all ingredients were held constant to insure an accurate measurement of the effectiveness of the surfactant combinations In Experimental Phase II (as shown in Table II) the levels of the anionic

TABLE I

DETERGENTS FORMULATED FOR PHASE I

Detergent Components*	Percent of Components				
	No. 1	No. 2	No. 3	No. 4	Tide**
A_1	12	12			NA
A_2			12	12	NA
N_1	8		8		NA
N_2		8		8	NA
HEC	7.5	7.5	7.5	7.5	0
STPP	20	20	20	20	51
Na_2SO_4	52.5	52.5	52.5	52.5	NA

*A_1 - sodium lauryl sulfate
A_2 - sodium p-tridecylbenzenesulfonate
N_1 - triton X-100, octylphenol-ethylene oxide condensate
N_2 - ethoxylated fatty alcohol
HEC - hydroxyethyl cellulose
STPP - sodium tripolyphosphate
Na_2SO_4 - sodium sulfate
NA - not available

**Tide currently available contain 25 percent STPP.

TABLE II

DETERGENTS FORMULATED FOR PHASE II

Experiment No.	Percent of Components				
	Anionic	Nonionic	HEC	STPP	Na_2SO_4
9	8	6	7.5	12	66.5
10	8	6	7.5	16	62.5
11	8	6	7.5	20	58.5
25	8	8	7.5	12	64.5
15	8	8	7.5	16	60.5
20	8	8	7.5	20	56.5
17	8	10	7.5	12	62.5
27	8	10	7.5	16	58.5
4	8	10	7.5	20	54.5
33	12	6	7.5	12	62.5
36	12	6	7.5	16	58.5
24	12	6	7.5	20	54.5
2	8	12	7.5	12	60.5
3	8	12	7.5	16	56.5
28	8	12	7.5	20	52.5
31	12	8	7.5	12	60.5
35	12	8	7.5	16	56.5
5	12	8	7.5	20	52.5
13	12	10	7.5	12	58.5
18	12	10	7.5	16	54.5
30	12	10	7.5	20	50.5
16	16	6	7.5	12	58.5
22	16	6	7.5	16	54.5
19	16	6	7.5	20	50.5
21	12	12	7.5	12	56.5
14	12	12	7.5	16	52.5
12	12	12	7.5	20	48.5
34	16	8	7.5	12	56.5
32	16	8	7.5	16	52.5
8	16	8	7.5	20	48.5
1	16	10	7.5	12	54.5
23	16	10	7.5	16	50.5
6	16	10	7.5	20	46.5
26	16	12	7.5	12	54.5
7	16	12	7.5	16	50.5
29	16	12	7.5	20	46.5

surfactant, nonionic surfactant, and STPP were varied, HEC was held at a constant, and sufficient sodium sulfate was used for each detergent to bring the ingredient total to 100 percent.

The procedure for formulating the detergents was as follows:

1. An analytical balance was used to weigh each of the ingredients. A total of 1.5 grams of each detergent was formulated.
2. Distilled water was used to dissolve and dilute the 1.5 grams of of ingredients to yield one liter of detergent solution.
3. Two hundred milliliters of detergent solution were measured and put in the canisters of the Launder-O-Meter.

Experimental Phase I

The statistical design for Phase I was a factorial design with five detergents, three pH values, two fabrics, and three replications. Because of the physical arrangement of the Launder-O-Meter, the design was blocked on fabrics. Six blocks were needed to complete this phase.

In Phase I, five detergents at three pH levels were tested on two fabrics to determine their effectiveness in soil removal and redeposition. There were three replications to ensure accuracy.

1. Reflectance measurements on the soiled and unsoiled portions of the fabric were taken using the Hunter Color Difference Meter. The readings used in this study were the L, a, and b. The (L) reading measures whiteness by determining a point on a scale of 0, representing black, to 100, representing white. The (a) reading measures red to green, red being on the positive side and green being on the negative side. The (b) reading measures

the yellow to blue cast, a positive reading indicates yellow and a negative reading indicates blue (15). The initial reflectance readings were referred to as R_o for the unsoiled portion and R_s for the soiled portion.

2. For each of the five detergent solutions, three canisters were filled with 200 ml per canister. The pH of the detergents was adjusted to 8, 9, or 10 for the three different canisters. The pH meter was used in obtaining the proper adjustments.
3. One swatch of fabric was placed in each canister with the detergent solutions and 10 stainless steel balls were added, as specified by AATCC Test Method No. 61-1970. The canisters were then randomly placed in the Launder-O-Meter.
4. Each experiment was run at 120^{o}F for 30 minutes.
5. Each sample was individually rinsed in approximately 200 ml of distilled water until the water was clear.
6. The samples were laid on paper towels to dry, then pressed with a warm iron on the unsoiled side of the fabric.
7. The second reflectance readings on the soiled portion of the fabric, recorded as R_L, and on the unsoiled portion, recorded as R_R, were taken.
8. The percent soil removal was calculated using the formula:

$$\% \text{ SR} = \frac{R_L - R_s}{R_o - R_s} \times 100$$

The percent redeposition was calculated using the formula:

$$\% \text{ SD} = \frac{R_o - R_R}{R_o} \times 100$$

Experimental Phase II

The purpose of Phase II was to determine the most effective level of the two surfactants found to be superior in the first phase of this research. The procedure for Phase II is the same as Phase I, except that no adjustment in solution pH was made.

The statistical design used for Phase II was a full factorial with three levels of anionic surfactant, four levels of nonionic surfactant, three levels of sodium tripolyphosphate, two fabrics, and three replications. The design was again blocked in fabric, but two loadings were needed per block. A total of twelve loadings was needed for this phase.

Evaluation

Phase I was evaluated with a three way analysis of variance using the soil removal and soil redeposition as derived from reflectance data. The independent variables were fabric, detergent, and pH level. The dependent variables were percent soil removal and percent soil redeposition. The IBM 360 Computer in the University of Tennessee Computing Center was used for analysis of the data.

Phase II was evaluated with a four way analysis of variance, again using soil removal and redeposition as derived from the reflectance data. The independent variables were fabric, level of anionic surfactant, level of nonionic surfactant, and level of phosphate. The dependent variables were percent soil removal and percent soil redeposition. Effects were regarded as significant at the 0.05 probability level.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the experimental work will be presented in two main sections: (1) Preliminary Investigation of Effects of pH and Surfactant Types on Soil Removal, and (2) Optimization of Detergent Formulation for Soil Removal.

Preliminary Investigation of Effects of pH and Surfactant Types on Soil Removal (Phase I)

A full factorial experiment was carried out using the following design:

Variable	Levels
Detergent	5
pH	3
Fabrics	2

The five detergents studied were formulated as previously indicated in Table I (page 19). The four experimental detergents all contained 20 percent sodium tripolyphosphate whereas commercial Detergent 5, Tide, contained, accoridng to its label, 51 percent sodium tripolyphosphate. To compensate for the reduced phosphate, the experimental detergents contained a high level of antiredeposition agent, hydroxyethyl cellulose (HEC) (7.5 percent) compared to 1 percent carboxymethyl cellulose used in Tide. The four experimental detergents differed in the nature of the surfactants used; all employed a mixed anionic/nonionic surfactant system with 12 percent anionic and 8 percent nonionic surfactants, but the

surfactant combinations differed in all four. The pH of each detergent solution was adjusted to either 8, 9, or 10 according to the design. The two fabrics were presoiled cotton with a wash/wear (Rigmel) finish and a presoiled polyester/cotton blend with a durable press (Rigmel) finish; both fabrics were obtained from Test Fabircs. The entire 5 × 3 × 2 factorial experiment was replicated three times in six blocks, based on fabric type.

Dependent variables evaluated were soil removal and soil redeposition each derived from reflectance measurements before and after exposure of the fabric to the detergent solution. Results of the experiments are given in Table III, showing percent soil removal for each detergent, fabric, and pH, and in Table IV, showing percent soil redeposition for each treatment combination.

These results were analyzed by a Three-Way Analysis of Variance, using the SAS programs on the University of Tennessee IBM 360 computer system. Results of the ANOVAs are given in Tables V and VI for soil removal and redeposition, respectively.

The analysis of variance for soil removal shows the three main effects all to be very highly significant. Inspection of Table III shows that the commercial detergent, Tide, had the highest values for soil removal and that the four experimental detergents ranked in the following order, from best to worst: 4, 3, 1, and 2. This table shows that pH values of 9 and 10 were both better for soil removal than was pH 8. Table III also shows that soil removal from the cotton fabric was better than that from the polyester/cotton fabric.

TABLE III

PERCENT SOIL REMOVAL FOR TREATMENT COMBINATIONS

Detergent	pH	Percent Soil Removal*	
		Fabric 1 (polyester/cotton)	Fabric 2 (cotton)
1	8	16.2	23.9
	9	19.5	25.6
	10	22.7	28.1
2	8	14.5	24.0
	9	20.3	25.6
	10	20.1	26.7
3	8	19.8	27.2
	9	22.1	27.7
	10	23.9	27.6
4	8	20.5	27.5
	9	24.1	28.5
	10	25.3	29.0
5	8	24.2	29.2
	9	27.5	31.5
	10	26.0	31.1

*This figure represents the average percent soil removal for the three replications.

TABLE IV

PERCENT SOIL REDEPOSITION FOR TREATMENT COMBINATIONS

Detergent	pH	Percent Soil Redeposition*	
		Fabric 1 (polyester/cotton)	Fabric (cotton)
1	8	1.497	0.650
	9	0.690	0.647
	10	0.373	0.397
2	8	0.547	0.397
	9	0.327	0.360
	10	0.257	0.357
3	8	0.363	-0.003
	9	0.180	0.183
	10	0.071	0.360
4	8	-0.071	0.143
	9	-0.183	0.653
	10	0.071	0.613
5	8	-0.133	0.253
	9	0.147	-0.147
	10	0.147	-0.037

*This figure represents the average percent soil removal for the three replications.

TABLE V

THREE WAY ANOVA FOR PERCENT SOIL REMOVAL

Source	DF	Sum of Squares	Mean Square	F Value	Prob.
Detergent	4	468.8	117.2	58.1	.0001***
Fabrics	1	752.0	752.0	372.9	.0001***
pH	1	187.3	93.6	46.4	.0001***
Detergent × Fabric	4	17.46	4.36	2.17	.0834
Detergent × pH	8	34.68	4.34	2.15	.0447*
Fabric × pH	2	26.89	13.44	6.67	.0028**
Detergent Fabric × pH	8	12.03	1.50	0.75	.65

***Very highly significant

**Highly significant

*Significant

TABLE VI

THREE WAY ANOVA FOR PERCENT SOIL REDEPOSITION

Source	DF	Sum of Squares	Mean Square	F Value	Prob.
Detergent	4	4.838	1.209	10.128	0.0001***
Fabric	1	0.063	0.063	0.527	0.5224
pH	2	0.237	0.118	0.990	0.6206
Detergent × Fabric	4	2.019	0.505	4.226	0.0048**
Detergent × pH	8	1.479	0.185	1.549	0.1602
Fabric × pH	2	0.499	0.249	2.088	0.1311
Detergent × Fabric × pH	8	1.341	0.168	1.404	0.2138

***Very highly significant

**Highly significant

The interaction of fabric and pH was found to be highly significant and the interaction of detergent and pH was found to be significant. Inspection of the data in Table III shows that the best results were obtained for Fabric 2, the cotton, and at higher pH's.

Results of the ANOVA for redeposition tend to support the conclusions reached above regarding the detergents. Table IV shows that the commercial detergent, Tide, had the lowest values for soil redeposited on the fabric. The four experimental detergents ranked in the following order from best to worst: 4, 3, 2, and 1. Tables IV and VI show that no significant differences in redeposition were found among the three pH levels studied. There was also found to be no difference in fabrics where redeposition was concerned. The interaction between detergent and fabric was found to be highly significant for redeposition. Table IV shows the best results were obtained for Fabric I, polyester/cotton, with detergent formula 4.

Based on these results, the surfactant system used in Detergent 4, sodium tridecylbenzenesulfonate (Conoco C-650) as the anionic surfactant and exthoxylated fatty alcohol (Alfonic 1412-6) as the nonionic surfactant, was selected for the second phase of this study. Since there was little difference in soil removal for pH 9 and pH 10, and since the detergents as formulated had a natural pH of 9.2 to 9.6, the decision was made to use the experimental detergents as formulated in the second phase of the study, without making any pH adjustments.

Optimization of Detergent Formulation for Soil Removal (Phase II)

A full factorial experiment was carried out using the following design:

Variables	Levels
Phosphate	3
Anionic	3
Nonionic	4
Fabric	2

The thirty-six detergent formulations studied were formulated as indicated in Table II, page 20. There were three levels of sodium tripolyphosphate;' 12, 16 and 20 percent. From the first phase of this research the preferred surfactant combination was found to be Conoco C-650 (anionic) and Alfonic 1412-6 (nonionic). Levels of these used were 8, 12, 16 percent for the anionic; and 6, 8, 10, and 12 percent for the nonionic. The level of the antiredeposition agent, hydroxyethyl cellulose (HEC), was held constant at 7.5 percent. The amount of sodium sulfate, inert builder, was computed to give each detergent formula a 100 percent total. The two fabrics were presoiled cotton with a wash/wear (Rigmel) finish and presoiled polyester/cotton blend with a durable press (Rigmel) finish; both fabrics were obtained from Test Fabrics. The entire $3 \times 3 \times 4 \times 2$ factorial experiment was replicated three times in six blocks, two loading per block, based on fabric type.

Dependent variables evaluated were soil removal and soil redeposition. Reflectance measurements were taken before and after each fabric swatch was subjected to the detergent solution. Results of the experiment are

given in Table VII, showing percent soil removal for each detergent for formula, and in Table VIII, showing percent soil redeposition for each treatment combination.

The results were analyzed using the four way analysis of variance using the SAS programs on the University of Tennessee IBM 360 computer. Results of the ANOVA's are given in Table IX for soil removal and Table X for soil redeposition.

The analysis of variance for soil removal shows significance for three main effects, phosphate level, anionic surfactant level, and fabric type, as well as three interactions; anionic surfactant level by nonionic surfactant level; phosphate level by anionic surfactant level by nonionic surfactant level; and phosphate level by anionic surfactant level by nonionic surfactant level by fabric type.

The phosphate level was found to be quite significant (Prob. = 0.0054). Soil removal as a function of phosphate level is shown in Figure 1. Inspection of this graph shows that higher levels, 16 percent and 20 percent, of phosphate increases soil removal.

The anionic surfactant level was also found to be significant (Prob. = 0.0283). Figure 2 shows soil removal in relation to anionic surfactant level. This graph shows the higher levels, 16 percent, of anionic surfactant greatly increase soil removal.

The variable fabric was found to be significant at the 0.0001 level. Table XI shows the cotton fabric, Fabric II, to have the higher percentage of soil removal.

TABLE VII

PERCENT SOIL REMOVAL FOR TREATMENT COMBINATIONS

Exp. No.	Detergent Composition* Percent A	N	P	Percent Soil Removal** Fabric 1 (polyester/cotton)	Fabric 2 (cotton)
9	8	6	12	25.28	26.26
10	8	6	16	26.46	26.89
11	8	6	20	24.59	28.81
25	8	8	12	24.64	27.14
15	8	8	16	26.33	26.36
20	8	8	20	26.32	28.44
17	8	10	12	21.35	27.71
27	8	10	16	25.80	27.75
4	8	10	20	25.74	27.02
33	12	6	12	26.46	27.04
36	12	6	16	26.33	29.05
24	12	6	20	25.62	28.62
2	8	12	12	22.91	27.43
3	8	12	16	25.41	28.10
28	8	12	20	28.16	27.32
31	12	8	12	29.00	27.23
35	12	8	16	26.34	28.76
5	12	8	20	24.02	26.71
13	12	10	12	23.21	26.79
18	12	10	16	28.64	29.08
30	12	10	20	29.88	28.71
16	16	6	12	24.59	28.48
22	16	6	16	26.32	28.99
19	16	6	20	25.14	27.94
21	12	12	12	24.10	26.54
14	12	12	16	25.86	27.06
12	12	12	20	21.56	27.85
34	16	8	12	23.18	28.48
32	16	8	16	26.67	28.62
8	16	8	20	26.67	28.75
1	16	10	12	25.42	26.44
23	16	10	16	25.70	28.65
6	16	10	20	23.61	28.14
26	16	12	12	27.15	28.53
7	16	12	16	25.65	27.49
29	16	12	20	26.92	28.61

*A = Anionic N = Nonionic P = Phosphate

**This figure represents the average percent soil removal for the three replications.

TABLE VIII

PERCENT REDEPOSITION FOR TREATMENT COMBINATIONS

Exp. No.	Detergent Composition* Percent A	N	P	Percent Soil Removal** Fabric 1 (polyester/cotton)	Fabric 2 (Cotton)
9	8	6	12	-0.401	0.896
10	8	6	16	-0.769	0.931
11	8	6	20	-0.327	0.787
25	8	8	12	0.145	0.680
15	8	8	16	-0.254	0.000
20	8	10	20	0.254	0.789
17	8	10	12	-0.364	0.789
27	8	10	16	0.145	0.428
4	8	10	20	-0.254	0.792
33	12	6	12	0.362	0.574
36	12	6	16	-0.037	0.539
24	12	6	20	0.181	0.538
2	8	12	12	-0.400	0.717
3	8	12	16	-0.400	0.394
28	8	12	20	-0.073	0.394
31	12	8	12	-0.001	0.358
35	12	8	16	0.327	0.682
5	12	8	20	-0.509	0.896
13	12	10	12	-0.546	0.824
18	12	10	16	-0.510	0.717
30	12	10	20	0.000	0.538
16	16	6	12	-0.218	0.827
22	16	6	26	-0.400	0.645
19	16	6	20	-0.035	0.180
21	12	12	12	0.070	0.753
14	12	12	16	-0.8-1	0.717
12	12	12	20	-0.290	0.752
34	16	8	12	0.472	0.610
32	16	8	12	0.363	0.789
8	16	8	20	-0.656	0.931
1	16	10	12	-0.577	0.969
23	16	10	16	0.291	0.537
6	16	10	20	-0.546	1.000
26	16	12	12	0.217	0.538
7	16	12	16	-0.364	0.967
29	16	12	20	-0.109	0.503

* = Anionic N = Nonionic P = Phosphate

**This figure represents the average percent soil redeposition for the three replications.

TABLE IX

FOUR WAY ANOVA FOR PERCENT SOIL REMOVAL

Source	DF	Sum of Squares	Mean Square	F Value	Prob.
Phos.	2	43.96	21.98	5.486	0.0054***
Anionic	2	29.04	14.52	3.625	0.0283**
Nonionic	3	2.74	0.81	0.228	0.8771
Fabric	1	303.48	303.48	75.749	0.0001***
Phos. × An.	4	24.07	6.00	1.499	0.2046
Phos. × Non	6	21.14	3.52	0.879	0.5129
An. × Non.	6	68.73	17.46	2.059	0.0117**
Phos. × Fab.	2	4.14	2.07	0.576	0.6035
An. × Fab.	2	6.59	3.29	0.822	0.5549
Non. × Fab.	3	1.12	0.37	0.093	0.9629
Phos. × An. × Non.	12	97.28	8.11	2.023	0.0259**
Phos. × An. × Fab	4	19.98	4.99	1.247	0.2933
Phos. × Non. × Fab	6	11.66	1.94	0.485	0.8197
An. × Non. × Fab.	6	29.86	4.98	1.242	0.2875
Phos. × An. × Non. × Fab.	12	102.24	8.52	2.127	0.0185**

***Very highly significant

**Highly significant

*Significant

TABLE X

FOUR WAY ANOVA FOR PERCENT SOIL REDEPOSITION

Source	DF	Sum of Squares	Mean Square	F Value	Prob.
Phos.	2	0.909	0.456	1.241	0.2918
Anionic	2	0.913	0.457	..247	0.2901
Nonionic	3	1.529	0.509	1.391	0.2468
Fabric	1	45.329	45.329	123.738	0.0001**
Phos. × An.	4	0.722	0.181	0.493	0.7439
Phos. × Non.	6	1.841	0.307	0.838	0.5439
An. × Non.	6	3.029	0.505	1.378	0.2265
Phos. × Fab.	2	0.423	0.241	0.659	0.5236
An. × Fab.	2	1.624	0.812	2.217	0.1106
Non. × Fab.	3	0.643	0.214	0.585	0.6301
Phos. × An. × Non.	12	3.733	0.311	0.849	0.6006
Phos. × An. × Fab.	4	0.391	0.098	0.267	0.8983
Phos. × Non. × Fab.	6	3.879	0.647	1.765	0.1097
An. × Non. × Fab.	6	7.527	1.254	3.424	0.0038**
Phos. × An. × Non. × Fab.	12	8.248	0.687	1.876	0.0417*

***Very highly significant

*Significant

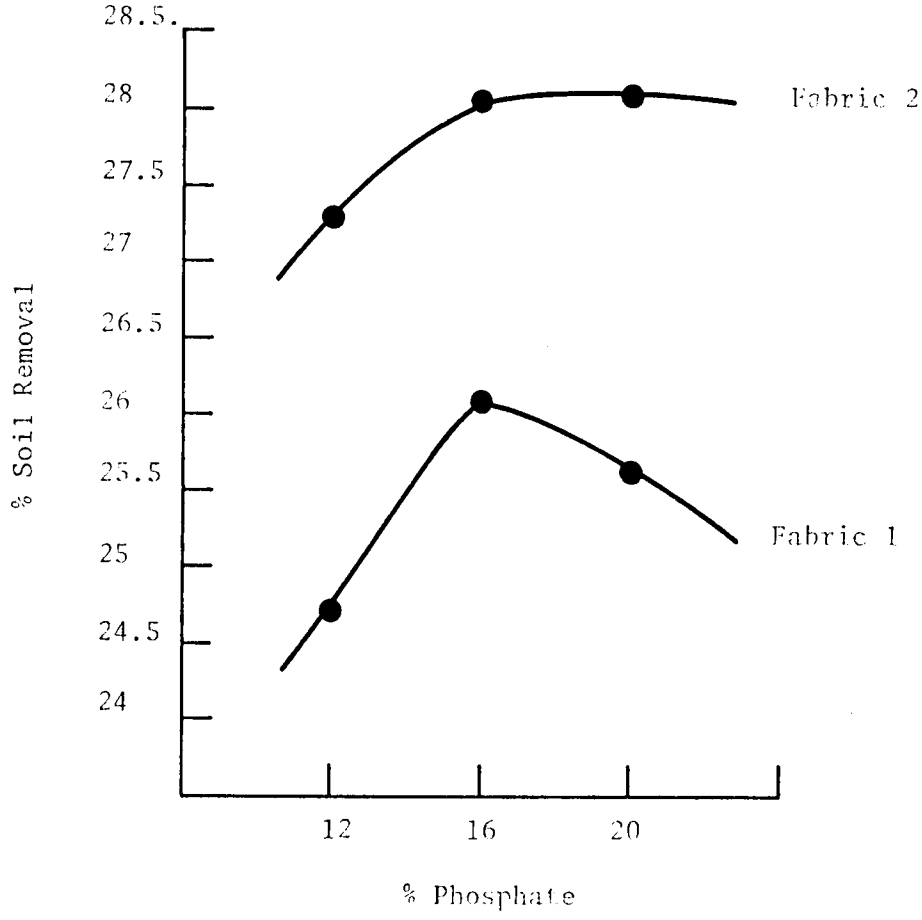


Figure 1. Mean values of percent soil removal for detergents as a function of phosphate level.

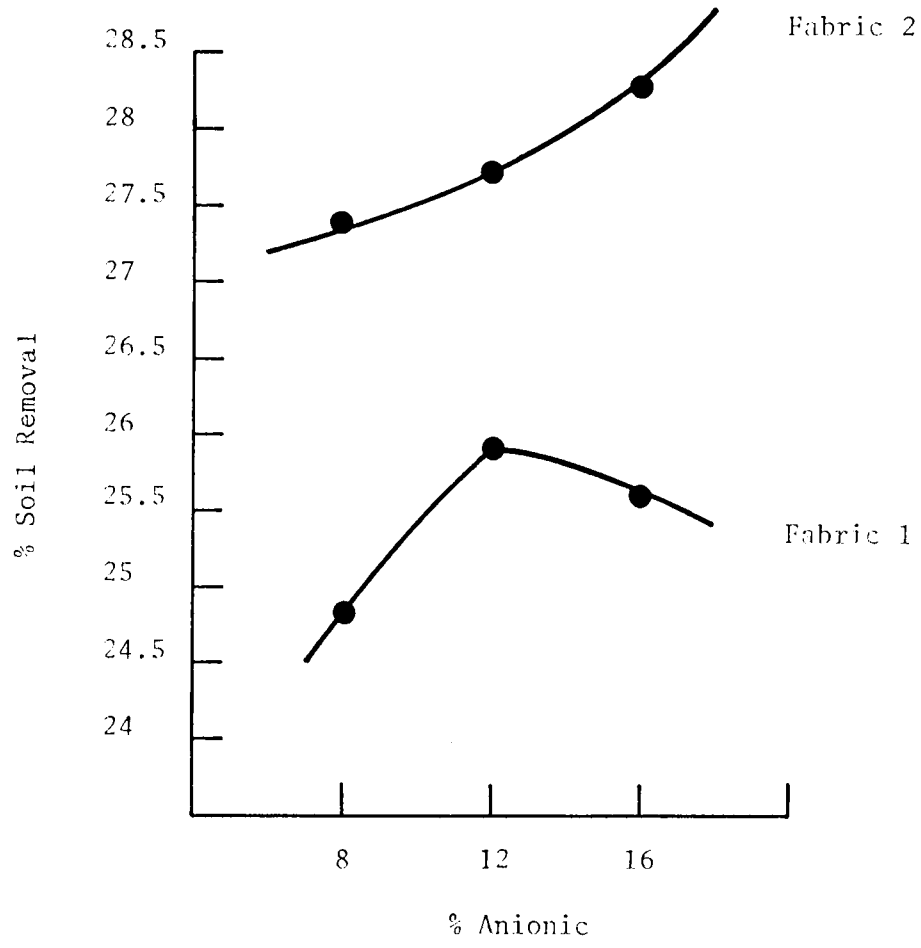


Figure 2. Mean values of percent soil removal for detergents as a function of anionic level.

Table XI

Percent Soil Removal for Fabric Types

Fabrics	Composition	Number of Observations	Percent Soil Removal
1	polyester/cotton	108	25.46
2	cotton	108	27.83

The anionic surfactant level by nonionic surfactant level was found significant (Prob. = 0.0117). Figure 3 shows the moderate level of anionic surfactant, 12 percent, to work best with the moderate and low levels of nonionic surfactant, 6, 8, and 10 percent. The higher level of anionic surfactant, 16 percent, works best with the higher level of nonionic surfactant, 12 percent.

The interaction between phosphate, anionic surfactant level, and nonionic surfactant level was found to be significant at the 0.0259 level. Figure 4 shows the percent soil removal for Fabric I polyester cotton in relation to anionic surfactant level, nonionic surfactant level and phosphate level.

Figure 4 (a) indicates that a low level of anionic surfactant, 8 percent, needs a high level of nonionic surfactant, 12 percent, and a high level of phosphate, 20 percent, for superior soil removal. Figure 4 (b) shows that a 12 percent anionic surfactant, the higher levels of phosphate, 16 and 20 percent, work well with the low to moderate levels of nonionic, 6, 8, and 10 percent. If the anionic surfactant level is

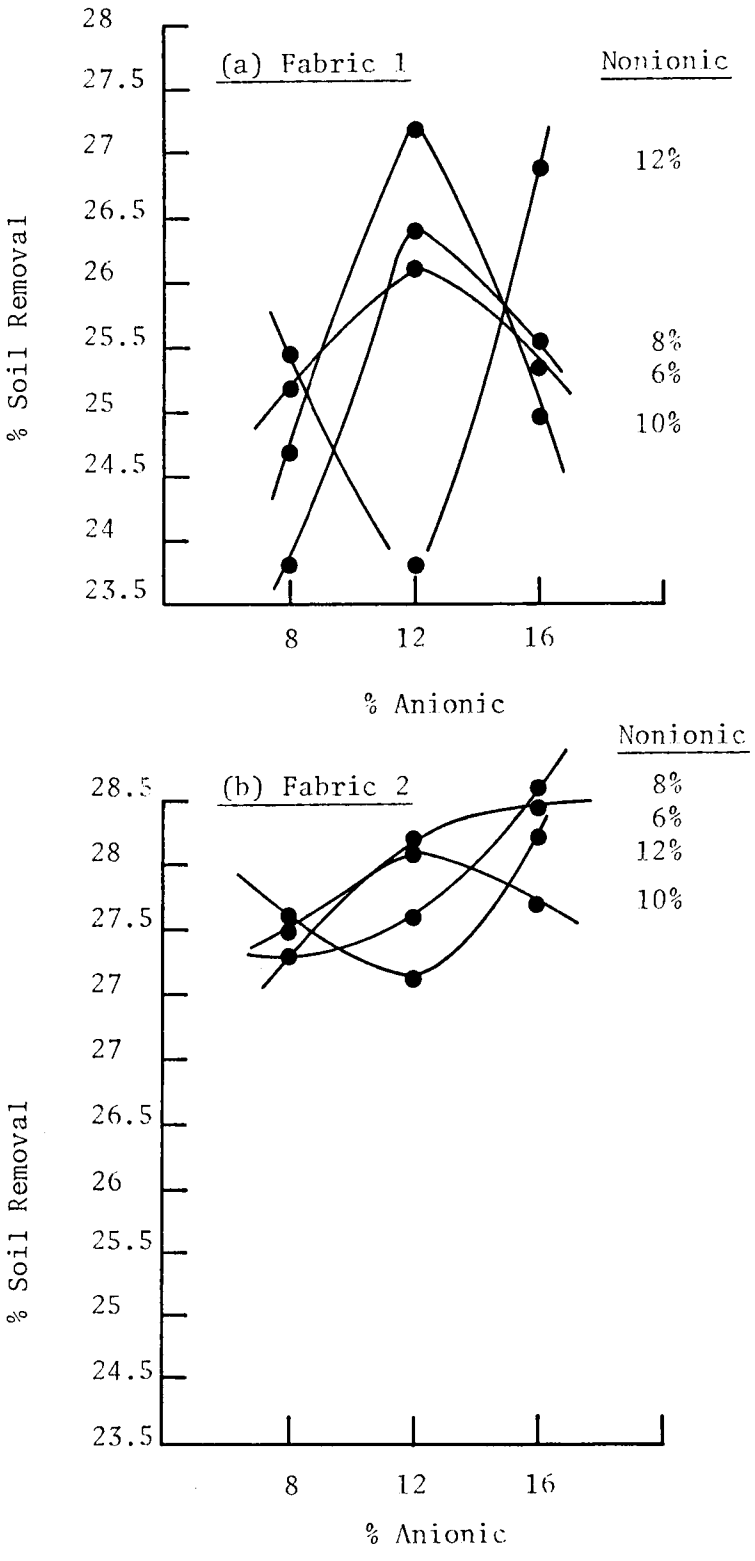


Figure 3. Mean values of soil removal for anionic and nonionic levels in relation to fabric types.

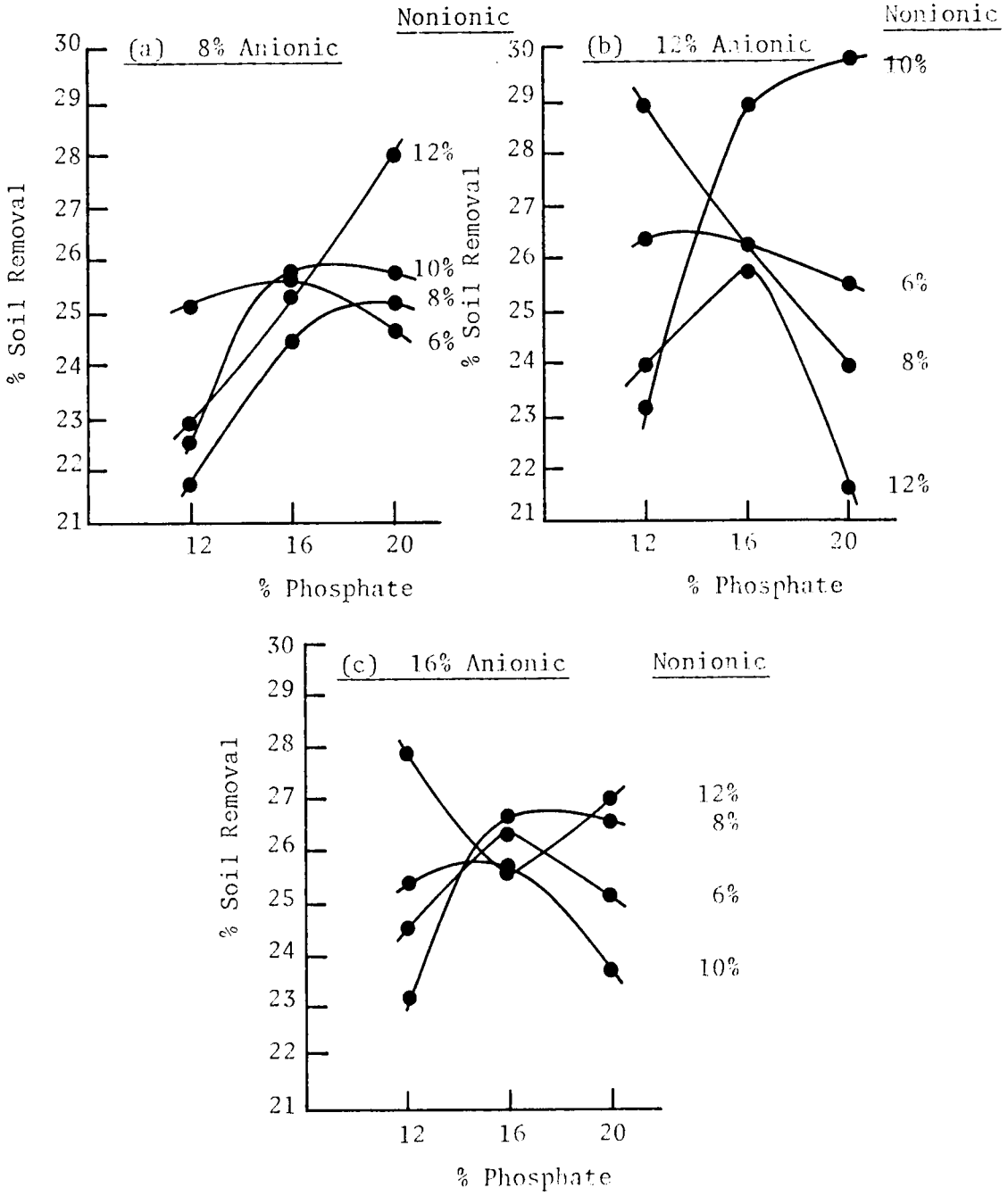


Figure 4. Mean values of soil removal for anionic, nonionic and phosphate interaction for Fabric 1.

increased to 16 percent, as represented in Figure 4 (c), the highest level, 12 percent, of nonionic is needed with the lowest level of phosphate, 12 percent for best soil removal. Figure 4 (c) also indicates that there is little apparent difference among the levels of nonionic surfactant used with the moderate level, 16 percent, of phosphate.

Figure 5 (a) shows the percent soil removal for Fabric 2, cotton, in relation to anionic surfactant level, nonionic surfactant level, and phosphate level. Figure 5 indicates that the low level of anionic surfactant, 18 percent, and the lower levels of nonionic surfactant, 6 and 8 percent, need the high level, 20 percent of phosphate for superior soil removal. Figure 5 (b) shows the moderate, level of anionic surfactant, 12 percent, to work best with the low to moderate, 6, 8,and 10 percent, level of anionic surfactant at the moderate, 16 percent, level of phosphate. Figure 5 (c) shows the only significant difference in percent nonionic surfactant used with 16 percent anionic surfactant to be at the low level, 12 percent, of phosphate. A detergent formulation with a low level of phosphate, 12 percent, needs the higher levels of nonionic surfactant, 10 and 12 percent, and anionic surfactant.

Based on the above, the best combination appears to be in the high range for anionic surfactant, 16 percent, nonionic surfactant, 12 percent and phosphate level, 20 percent. An alternative combination would be moderate levels of anionic surfactant, 10 percent, and phosphate, 12 percent.

The four way analysis of variance for percent soild redeposition shows one main effect to be significant, fabric types.

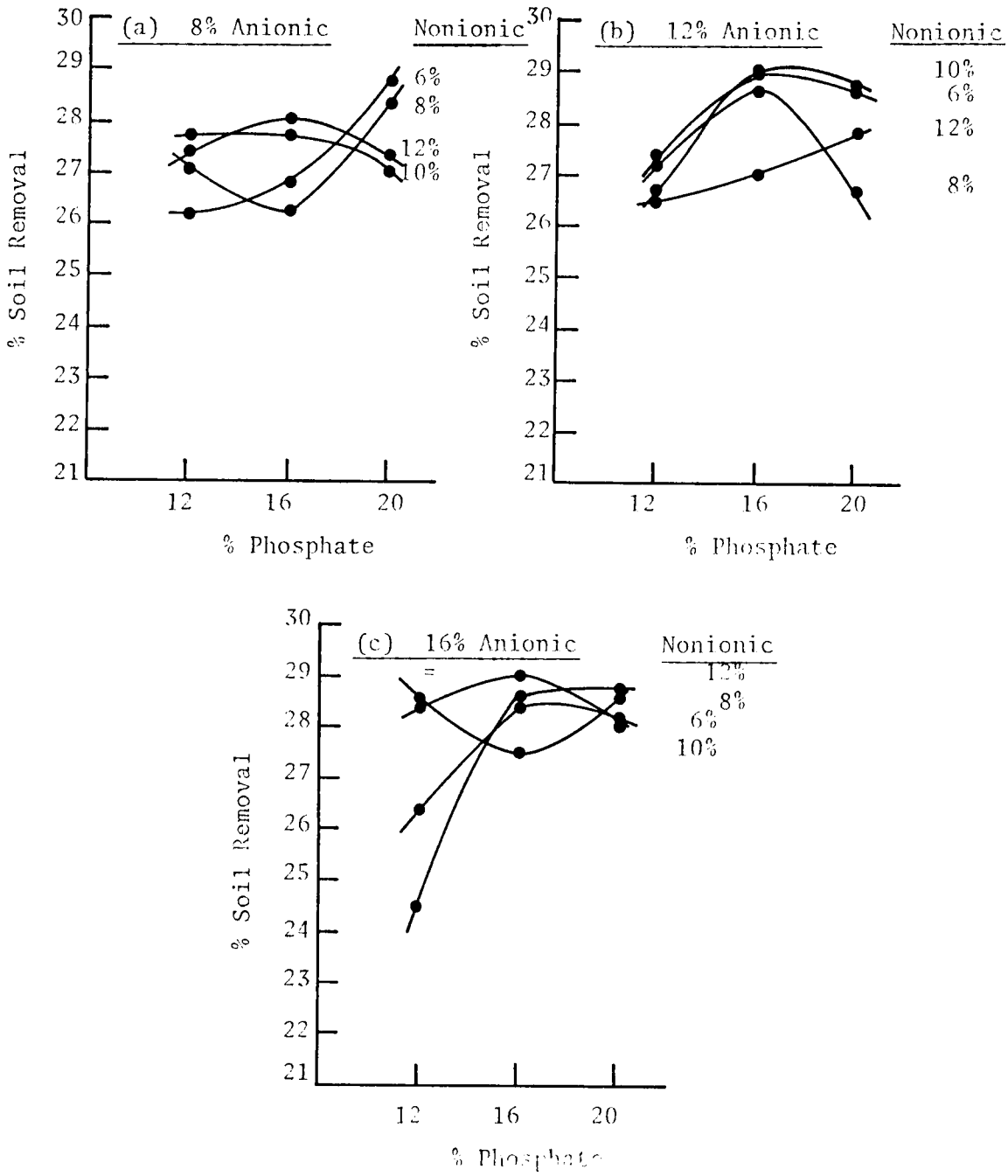


Figure 5. Mean values of soil removal for anionic, nonionic and phosphate interaction for Fabric 2.

Table XII shows Fabric 2, cotton, to have the higher percent soil redeposition. This outcome could be based on the finding that Fabric 2 had more soil removed from it, making more soil suspended in the wash liquor and available for redeposition. The negative value for redeposition indicates that the fabric was cleaner after washing than before washing.

Table XII

PERCENT SOIL REDEPOSITION FOR FABRIC TYPES

Fabrics	Composition	Number of Observations	Percent Soil Redeposition
1	polyester/cotton	108	-0.214
2	cotton	108	0.702

One three way interaction, anionic surfactant level by nonionic surfactant level by fabric type, was found to be significant (Prob. = 0.0038). The four way interaction, phosphate level by anionic surfactant level by nonionic surfactant level by fabric type, was also found to be significant (Prob. = 0.0417).

CHAPTER V

SUMMARY AND CONCLUSIONS

The objectives of this research were to evaluate low phosphate detergents which contain HEC as the antiredeposition agent using selected surfactant combinations and pH levels.

For the four formulated detergents used in Phase I the anionic surfactants were sodium lauryl sulfate and sodium p-tridecylbenzene-sulfonate, and the nonionic surfactants were an octylphenol—ethylene oxide condensate and an ethoxylated fatty alcohol. The detergents also contained sodium tripolyphosphate as the builder, sodium sulfate as an inert builder, and HEC as an antiredeposition agent. Detergent formulations are shown in Table I, page 19. The fifth detergent was commercial Tide.

Soil removal experiments were used to measure the ability of the detergent formulations to remove the oil bound carbon soil from soiled fabric. Soil redeposition experiments measured the ability of the detergent formulations to prevent the oily soil from redepositing onto clean fabric. The degree of soil removal and soil redeposition was determined by reflectance readings taken on the soiled and unsoiled portions of each fabric swatch before and after each washing. The two fabrics used were a presoiled cotton with a wash/wear finish and a presoiled polyester/cotton with a durable press finish.

Statistical analysis was based on the analysis of variance using percent soil removal and percent soil redeposition calculated from the

reflectance data. Analysis of variance was used to determine which detergent formulation was most effective in soil removal and soil redeposition. The ANOVA for soil removal showed the three main effects of detergent formulation, fabric types, and pH level, to be highly significant.

Of the four experimental detergents, detergent number 4 with sodium p-tridecylbenzesulfonate as the anionic surfactant and an ethyoxylated fatty alcohol as the nonionic surfactant, was found to be superior in soil removal ability. Detergent number 4, with 20 percent phosphate, was found to be similar in soil removal ability to Tide, with 51 percent phosphate.

For all five detergents tested, the degree for soil removal for the cotton fabric was superior to the percent soil removal for the polyester/cotton. There was also found to be a positive correlation between percent soil removal and pH level for all five detergents. The interaction between detergent and pH was also found to be significant. Detergents 4 and 5 had superior soil removal ability at the higher pH levels. The interaction between fabric type and pH showed the detergent formulations to have a higher degree of soil removal on Fabric 2, the cotton, at the pH levels of 9 and 10.

The ANOVA showed the main effect of detergent combinations to be significant for percent soil redeposition. Detergent formulations 3 and 5 showed the best results for soil redeposition. The detergent by fabric interaction for all treatment combinations showed detergent 4 allowed the least amount of redeposition of Fabric 1.

Based on the above, Detergent 4 with sodium p-tridecylbenzenesulfonate as the anionic surfactant and an ethoxylated fatty alcohol as the nonionic surfactant, was found to contain the most effective surfactant combination for soil redeposition as well as for soil removal. Since there was little difference in soil removal for pH 9 and pH 10, and since the detergent as formulated had a natural pH of 9.2 to 9.6, the decision was made to use the experimental detergents as formulated in the second phase of the study, without making any pH adjustments.

The thirty-six detergents prepared for Phase II were formulated with varying amounts of the anionic surfactant and nonionic surfactant found to be superior in Phase I. There were three levels of anionic, 8, 12, and 16 percent, and four levels of nonionic, 6, 8, 10, and 12 percent. Three levels of phsophate, 12, 16, and 20 percent were introduced to find the most effective surfactant combination for each phosphate level.

Soil removal experiments were used to measure the ability of the detergents formulations to remove the oil bound carbon soil from the soiled fabric. Soil redeposition experiments measured the ability of the detergent formulation to prevent the oily soil from redepositing onto the clean fabric. The degree of soil removal and soil redeposition was determined by reflectance readings taken on the soiled and unsoiled portion of each fabric swatch before and after each washing. The two were presoiled cotton with a wash/wear finish and presoiled polyester/cotton with a durable press finish.

The statistical analysis was based on the analysis of variance using percent soil removal and percent soil redeposition calculated from the

reflectance data. The main effects of phosphate level, anionic surfactant level, nonionic surfactant level and fabric type were found to be highly significant for soil removal. The interactions of anionic surfactant level, and phosphate level by anionic surfactant level by nonionic surfactant level were found to be highly significant. The four way interaction of phosphate level by anionic surfactant level by nonionic surfactant level by fabric type was also found to be highly significant.

The four way interaction showed the best results for Fabric I to be with the detergent composition of 12 percent anionic, 10 percent nonionic and 20 percent phosphate. The moderate surfactant levels 12 percent anionic and 10 percent nonionic appear to work effectively with a high level of phosphate. The detergent composition with 16 percent phosphate needed a high level anionic surfactant, 16 percent, and a low level of nonionic surfactant, 6 to 8 percent, to be effective in soil removal. For the low phosphate (12 percent) detergent formulation, the anionic surfactant level of 12 percent and the nonionic surfactant level of 8 percent proved to be the most effective.

The four way interaction showed the best results at each phosphate level for Fabric 2 to be with the detergent compositions of 12 percent anionic surfactant, 10 percent nonionic surfactant and 16 percent phosphate, and 16 percent anionic surfactant, 10 percent nonionic surfactant, and 16 percent phosphate. The 16 percent phosphate level appeared to be the most effective in soil removal with a 12 to 16 percent anionic surfactant level and a 10 percent nonionic surfactant level. Of the detergent formulations with 20 percent phosphate, the 8 percent anionic surfactant level and the 6 percent nonionic level were found

to be superior in soil removal. The detergent formulations with 12 percent phosphate required a high level of surfactants, 16 percent anionic and 12 percent nonionic in order to be effective as a soil removing agent.

Based on the above, the most effective detergent formulation appeared to be composed of 12 percent anionic surfactant, 10 percent nonionic surfactant, and a phosphate level of 16 to 20 percent.

In evaluation of the effectiveness of detergent formulations, this research was limited to the evaluation of soil removal and soil redeposition in controlled laboratory conditions. Further research needs to be done on the effectiveness of these detergents at different water hardness levels. This study was limited to distilled water.

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APPENDIX

COMPOSITION OF SOIL APPLIED TO FABRICS

1.0 part	ethyl cellulose showing a viscosity of from 8 to 12 centipoises at 25°C. when 5 parts are dissolved in a mixture of 57 parts of toluene (ACS) and 38 parts of ethyl alcohol (ACS)
14.0 parts	naphtha
0.5 parts	butanol
2.0 parts	lampblack, conforming to the requirements of Fed. Spec. TT-L-70
2.5 parts	hydrogenated vegetable oil conforming to the requirements of Fed. Spc. EE-S-321
20.0 parts	mineral oil (U.S.P.) medicinal grade
0.8 parts	purified sodium alginate
57.1 parts	cold water
1.3 parts	cornstarch
0.5 parts	oleic acid (U.S.P.)
0.3 parts	morpholine solvent

VITA

Kathy Rhea Shelton, the daughter of Mrs. Neta Shelton and the late Mr. John H. Shelton, was born in Louisville, Kentucky, on April 26, 1950. She graduated from East High School, Memphis, Tennessee, in 1969. From 1968 to 1969 she attended Memphis State University. In 1969, she transferred to the University of Tennessee at Martin, and received her Bachelor of Science degree in June 1972, with a major in Home Economics. She was a member of Chi Omega Social Sorority.

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