THE EFFECT OF WATER LEVEL ON SOIL REMOVAL IN A HOME LAUNDRY SIMULATION

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CHAPTER I

INTRODUCTION

The late 1970's and early 1980's were the beginning of a new era for the United States. The Arab oil embargo of 1973 made Americans aware of their limited energy resources. Since then, progress has been made toward finding and utilizing newer and renewable energy sources. As a consequence of this movement coupled with rising inflation, the American consumer is learning to conserve, both due to cost and supply.

It has been estimated that 15 to 20 percent of the nation's energy is used in the home. This residential use is divided among many sections. Approximately 5.8 percent of home energy is used for laundry. This energy use can be broken down further. The largest amount of energy employed in home laundry, between 90 and 95 percent, is used to heat the water used (Schrage, 1980). The laundry equipment manufacturers have made energy saving improvements in washers and dryers. Schrage (1980) of Whirlpool has stated that the only remaining viable method to reduce energy use in the home laundry process is to reduce the amount of hot water used.

Two methods could be employed to reduce hot water use. An alternative in current practice involves changing from washing in hot water to warm or cold. The detergent industry has aided the consumer in this change by introducing detergents formulated especially for cooler water (Cowan, 1980). This change in laundry products and procedure has resulted in satisfactory washing.

A second method for reducing the amount of hot water used would be to reduce the level of water used in washing each load. In addition to saving energy, the citizens of the United States now need to start conserving water.

Water is one of the natural resources that man has always believed was available in abundant supply. Water is now becoming a more precious commodity. Droughts causing shortages of clean water are occurring throughout the country. Experts predict that of the 18 water resource regions in the United States, only three will have an adequate supply of water in the year 2000 (Is U. S. Running, 1977). As the population and level of technology increases, the demand for water rises even faster (Warning: Water Shortages Ahead, 1977). Very soon the people of the United States are going to have to confront the fact that fresh pure water is a limited resource and must be handled with care.

The public must learn to keep its water usage at reasonable and manageable levels. When residents of Marin County, California were faced with a severe drought in 1976-1977, they cut their water consumption by 65 percent (Yankelovich and Lefkowitz, 1980; Water: Time To Start Saving, 1978). The conservation habits stayed with the residents; a year after the drought ended water consumption was still between 25 and 45 percent lower than pre-drought days (Yankelovich and Lefkowitz, 1980; Water: Time To Start Saving, 1978).

Experts have attributed the success of this conservation to several factors. The first was the obvious shortage, affecting all the residents equally. A second was the assurance that each person could do his or her part and that each individual's participation would be important. Another factor was the local government's willingness to let the residents conserve in the way each desired (Yankelovich and Lefkowitz, 1980).

The consuming public can conserve if they see a real need. As the water shortage grows, the public will become more aware and perhaps more receptive to changes in their life styles. Yankelovich and Lefkowitz (1980) suggested that the public will make changes in their behavior if those changes are perceived as matters of personal choice, as viable alternatives to shortages.

Researchers are continuing to explore ways of offering choices in the area of residential water conservation. Home water usage can be divided into two categories: indoor and outdoor. Indoor water use accounts for about half of all residential consumption. An examination of indoor consumption revealed that laundry use accounts for about 20 percent of the indoor total (Milne, 1979). This water is most often used in a typical automatic clothes washer that has three cycles: wash, spray rinse, and deep rinse. The wash cycle uses about 20 gallons of water, followed by a spray rinse using three to four gallons and a final deep rinse cycle using 20 gallons. A common feature on many automatic washers is a load size selector. These selectors may have an infinite number of settings or settings for small, medium and large loads. The medium setting uses approximately two-thirds of the amount of water in the wash and deep rinse cycles as the large setting.

If a satisfactory laundering process could be determined which would allow a full load of clothes to be washed on a reduced setting of water, substantial residential savings could be realized. The average family using a medium water setting of approximately 30 gallons per load, instead of the large setting of approximately 43.5 gallons for each large load of clothes could save 13.5 gallons of water per load. During an average week, when five loads of clothes are washed, the water savings would be 67.5 gallons. This seems like a small amount and of little consequence. The residents of Marin County, California have shown that it is the small savings that add up and are important. At the end of a year 3,510 gallons would have been saved. To show the significance nationally savings can be computed using data from the United States Department of Commerce 1970 Census of Housing: 71.1 percent (48,184,405) of the 67.7 million housing units in the United States had clothes washers. If each household could follow this procedure for reducing water consumption, 1.6913×10^{11} gallons per year could be saved.

Purpose and Objectives

The purpose of the study was to discover the effectiveness of a reduced water level on the removal of soil from clothes in a home laundry simulation. The following objectives were formulated to accomplish the purpose of this study:

1. To compare the effect of a reduced water level on soil removal with the soil removal of a standard water level.

2. To determine whether detergent composition affects soil removal at specified water levels.

3. To determine whether water temperature affects soil removal at specified water levels.

Hypothesis

The null hypothesis formulated for this study was as follows:

H_1: There will be no significant difference between the amount of soil removed in a reduced water level and in a standard water level using (a) three different detergents, and (b) three different water temperatures.

Assumptions and Limitations

The assumptions formulated for this study were as follows:

1. The methods used in this study were comparable to home laundry methods.

2. The standard soil used in this study was representative of types of soil found on clothes.

3. The readings from the reflectometer were an adequate indicator of the amount of soil removed.

The limitations of this study were the following:

1. Only one reflectometer filter and reading were used at each interval in this study.

2. The hardness of the water used in the study was not adjusted.

3. The composition of the water used in the study was not adjusted.

4. Only three detergents were used with the standard soil and fabric used in this study.

Definitions

The following definitions have been established to give the same connotation of the words whenever they are used in the report:

Reduced Water Level - The level of water (29 gallons) used at the medium load setting of a Maytag model A310, a typical automatic clothes washer.

Standard Water Level - The level of water (36 gallons) used at the large load setting of a Maytag model A310, a typical automatic clothes washer.

Cold Water - The temperature of the cold water used in the wash cycles was 70°±5°F.

Warm Water - The temperature of the warm water used in the wash cycles was 100°±5°F.

Hot Water - The temperature of the hot water used in the wash cycles was 130°±5°F.

Anionic Detergent - A detergent that contains a surfactant that ionizes in water, and carries a negative charge.

Nonionic Detergent - A detergent that contains a surfactant that does not ionize, but acts as an electrically neutral unit when dissolved in water.

Cold Water Anionic Detergent - A detergent that has been specially formulated for cold water wash, that contains an anionic surfactant.

Surfactant - A surface active or wetting agent that reduces the surface tension of the washing solution.

CHAPTER II

REVIEW OF LITERATURE

There are many factors that affect the removal of soil from laundry. These include soil composition, detergent composition, type of equipment used, and water temperature. Other factors that need consideration for their importance to this study are mechanisms of soil removal, measures of cleanliness and the transference of laboratory results to actual home use. In this chapter the literature related to the above factors will be reviewed.

Soil Composition

Soil has been described as matter out of place (Price, 1952; Rice, 1964, Hofenk-de Graaf, 1968, Kissa, 1971a). More definitive descriptions of soil composition have been made. Soils encountered in the laundry were first separated into three classes in 1922 (Niven, 1950). These classes were (1) water soluble, (2) water insoluble, and (3) earthy inactive substances. Niven conducted an analysis of soil found in laundry and developed another classification scheme for soils:

1. Water soluble organic and inorganic materials.
2. Water insoluble inorganic materials.
3. Water soluble inert organic material.
4. Water insoluble reactive organic material.

Shimauchi and Mizushima (1968) stated that there were two major components of soil. The first component was fatty soil originating from perspiration and skin fat. In his study of laundry soil, Brown (1947) concentrated his efforts on oily soil. He analyzed oily matter present from one wearing, and found fatty acids, liquid fats, and hydrocarbons. Spangler, Cross and Schaafsma (1965) identified the following ten synthetic body sebum components as constituents of human body sebum. They are olive oil, spermacetic wax, coconut oil, oleic acid, palmitic acid, paraffin wax, stearic acid, squalene, cholesterol and linolic acid.

The second major component of soil identified by Shimauchi and Mizushima (1968) was that of particulate soil originating from air-borne dirt. Rounds, Purchase and Smith (1973) stated that the most common element of particulate soil is clay minerals. In an earlier research study on airborne particulate soil, Sanders and Lambert (1950) analyzed ordinary street dirt from six cities in the United States. The results, all very similar, indicated the presence of more silica and less carbon than the researchers expected. In their study of mass transfer in a washing machine, Ganguli and vanEenburg (1980) considered three components of laundry soil. They were liquid fatty oils, finely divided solids and pigments.

Smith and Sherman (1969), following a different classification scheme, stated that there were three types of fabric soil of concern in a laundry situation. They were (1) fluid stains, both water and oil based ranging from water to baby oil to molten tar; (2) dry particulate matter; and (3) combinations of one or more fluids with particulate matter. Kissa (1971a) in his article on the kinetics of soil release concurred with Smith and Sherman (1969) when he offered the following method for classifying soils. The classes were liquid soil, solid or particulate soil and mixed soil containing both liquid and particulate soil.

Soil Removal

An understanding of the varied component nature of soil is important to those researching the principles and mechanics of soil removal. The AHEA Textile Handbook (1974) indicated that the method of soil removal should be partially determined by the kind of soil present.

Price (1952, pp. 61-62) has defined the process of soil removal as follows:

> Cleaning consists essentially of removing substances that we call 'dirt' from some surface, such as that of a textile fabric. . . . Although dirt is quite complex and may contain a variety of substances, it is always made up of a mixture of solid particles and oily matter. What we really do, then, when we clean is to remove a mixture of solid particles and oil from a given surface.

Hofenk-de Graaf (1968) offered a brief general description of the process of washing. She said that it is a dynamic process that involves the equilibrium expressed in the following equation:

dirt on fabric + washing liquid = fabric + washing liquid containing dirt.

Jayson (1959) gave a more detailed description of the sequence of soil removal. He listed the following six steps:

1. Detergent is absorbed at fabric interfaces and wets the air out of the oil and fabric.

2. The fatty components in the soil are emulsified.

3. The soil is broken up through the interaction of the detergent, the soil and agitation.

4. The soil begins to break away from the fabric.

5. The action of the detergent then separates the soil from the fabric.

6. The fabric then absorbs clean detergent, so that the soil is not redeposited.

Smith and Sherman (1969) described another cleaning process in their paper on textile characteristics and soil removal. The process of "rolling up" involves the progressive displacement of fluid soil from the textile surface by the detergent in the washing solution. Kissa (1971a) also discussed the rolling up process of soil removal. He stated that water-insoluble liquid soil will spontaneously release from fabrics during the rolling up process, to be removed through mechanical agitation and finally replaced by detergent.

Kissa (1971a) further stated that laundering is a nonequilibrium process, where the amount of soil removal depends on the removal rate and the washing time. The rate of soil removal is dependent on two factors. The first is the rate of spontaneous soil release, and the second is the rate of soil dislodgment by mechanical agitation. He explained that soil release occurs in three consecutive steps. The first step is that of induction or the process of water diffusing into the soiled fabric. During the first step the rate of soil release is slow. The second step is one of rapid soil release, during which the processes of rolling up, dislodgment and water diffusion are rapid. The final step occurs when the soil retention and removal rates become essentially the same (Kissa, 1971a, 1975).

Kissa (1975) discussed two important classes of soil removal mechanisms. The first is the sorption of water and detergents. This classification includes the above discussed rolling up of soil and the additional mechanisms of solubilization, penetration and emulsification. The second is that of mechanical work which consists of hydrodynamic flow, fiber flexing, abrasion and the swelling of the fiber finish. These two classes of soil removal mechanisms must both be present for adequate soil removal to occur.

Kissa (1979) provided yet another explanation of the process of soil removal. He stated that the removal of a soil particle involves breaking an adhesive bond between the soil and the fabric. The interworking of all mechanisms of soil removal is necessary for this process to be done effectively. The amount of soil remaining after laundering depends on the amount of soil on the fabric and the soil removal coefficient present due to laundering conditions.

Detergents

Soil removal or the cleaning process has been explained in the following way: "Cleaning is the process of removing foreign matter from places where it is not wanted" (Price, 1952, p. 11). The authors of Chemistry of Cleaning (1979) continued the above explanation by stating that the cleaning process usually implies the involvement of a liquid bath, usually water and additional substances to enhance the cleaning process.

Today the most common addition to laundry solutions is synthetic detergents. In 1966, Proctor and Gamble reported that 90 percent of the products used in general laundering are synthetic detergents. Commercially produced first in 1933 synthetic detergents have replaced soap in most washing solutions (Chemistry of Cleaning, 1979).

Synthetic detergents, while basically similar to soaps, possess some qualities that soaps do not. Synthetic detergents are made from petrochemicals and until recently have been cheaper to produce (Chemistry of Cleaning, 1979). Synthetic detergents do not form lime curd or scum when used in hard water (AHEA Textile Handbook, 1974; Household Soaps and Detergents, 1978; Cowan, 1980). Synthetic detergents can also be formulated for specific laundry tasks and are quite efficient (Price, 1952).

Synthetic detergents perform several basic functions that are common to other washing agents as well. These are (1) the enhancement of wetting of both soil and fabric, (2) the ability to emulsify and hold oily soil in suspension, and (3) the ability to be absorbed by the fabric surface, replacing the soil (Price, 1952; Wolfrom and Nussele, 1953; AHEA Textile Handbook, 1974). In addition to performing these functions, synthetic detergents must also contain the following qualities to be an effective cleaning agent. These are (1) the ability to dissolve in the specified water temperature and (2) to be chemically stable (Cowan, 1980).

Synthetic detergents are classified into three groups based on the type of surfactant present. The three classifications are anionic, cationic and nonionic, based according to the way ionization occurs. Anionic surfactants ionize in water and carry a negative charge. Cationic surfactants also ionize in water, but they carry a positive charge. Nonionic surfactants do not ionize in water, and therefore carry no charge.

The anionic and nonionic are the most suited for soil removal from fabrics (Price, 1952; Household Soaps and Detergents, 1978;

Cowan, 1980; Soaps and Detergents, 1981). Anionic detergents were the first important synthetic detergents (Price, 1952). However, nonionics have gained more widespread usage as the fiber content of the average washload has changed (Household Soaps and Detergents, 1978). Fort, Billica and Grindstaff (1966) reported that nonionic detergents were more effective than anionic detergents in removing body oil from polyester fabrics. Bowers and Chantrey (1969) stated that nonionic detergents were more effective than cationic or anionic detergents in soil removal from polyester/cotton blend fabrics.

Grindstaff, Patterson and Billica (1970) in a continuation of their earlier study found that more soil removal occurred if the following conditions were met: (1) nonionic detergents were used, (2) the detergent concentration in the washing solution was kept high enough, and (3) the first rinse water was cold.

As the above researchers indicated, there are many factors present in any given washing situation. Crowe (1943) identified factors of importance as length of wash cycle, water temperature, concentration and type of detergent and type of soil. Sisley (1947) cited factors that influence the effectiveness of a detergent: the nature of the detergent, the surface to be cleaned, the water used and the soil to be removed.

Cowan (1980) reported that the detergent industry, in response to demands for energy saving, has formulated detergents for use in cooler water. Sullivan (1967), using some of the newer synthetic detergents, found that detergents designed for use in cold water performed as well as regular detergents in hot water.

Water Temperature

Many factors affect soil removal in a given laundry situation (Crowe, 1943; Sisley, 1947). Furry (1948) reported that synthetic detergents were more effective at higher water temperatures. Galbraith (1960) agreed with Furry's research when she reported that washing at 120°F or 140°F will remove more soil than washing at lower temperatures. In that study, the above statement held true with all detergents, even those formulated for cold water. Anderson (1956) stated that water temperature was a significant factor in soil removal. Less soil was removed at lower water temperatures than was removed at higher water temperatures. In contrast to earlier work, Matthews (1965) and McClester (1965) in separate research studies found that the difference in soil removal at various water temperatures was minimal. Based on these results, McClester (1965, p. 83) stated that "water temperature may not be as important a factor in the laundering process as had been formerly believed." Bowers and Chantrey (1969) in their research report on soiling, confirmed that the washing temperatures had very little effect on the amount of soil removed.

However, Kissa (1971a) in his report on the kinetics of oily soil release stated that water temperature is an important factor. The temperature of the water affects the solubility of the detergent and the viscosity of liquid soil. The use of hot water for the most efficient soil removal is recommended in the AHEA Textile Handbook (1974) and by Lyle (1977).

Measures of Cleanliness

Kissa (1971b) discussed methods of measuring the amount of soil present on fabric. He indicated that there are three methods usually employed. They are chemical analysis, photometric measurement of reflectance loss and visual comparison to a standard. The actual amount present can only be determined through chemical or radioactive analysis, both of which are time-consuming and destructive processes. Photometric and visual determinations measure only the appearance of soil or cleanliness. Photometric evaluation is the least time-consuming and its results correlate closely with those obtained from visual evaluation (Matthews, 1965). Utermohlen and Ryan (1949) stated that the use of reflectometers or photometric measurements of reflectance was the most popular means of estimating soil removal and whiteness. Matthews (1965) reported that reflectometers are the most common tool used to evaluate soil removal.

Transference of Laboratory Results to Actual Use

Bowers and Chantrey (1969) in the report on soiling, discussed the interpretation of laboratory studies. They stated that "Conclusions drawn from laboratory soiling results must be interpreted with greater care than most laboratory evaluations" (p. 2). Actual soil and soiling conditions are very difficult to accurately duplicate in a laboratory setting. Kissa (1975) agreed that great care must be taken. Correlations are possible and much valuable information can be gained through carefully planned and interpreted laboratory studies.

As we have seen, soil and soil removal are complex phenomena (Crowe, 1943; Sisley, 1947). Actual wear studies are very time-consuming and have many variables that cannot be adequately controlled. Some of these variables have been described by Abbott (1971, p. 28) as follows:

1. No two persons will wash in identically the same way.
2. No two localities have identically the same water.
3. Consumers will wash with many different detergents.
4. Water temperature will vary greatly by washing machine as well as by delivery from the heater itself.
5. No two washing machines are identical.
6. No two laundry loads are identical.

Laboratory studies can control for the variables that enter a laundry research problem and therefore are the most frequently used method of laundry research (Bowers and Chantrey, 1969).

CHAPTER III

METHOD AND PROCEDURE

The present study was designed to determine the effectiveness of a procedure to reduce the amount of water and energy used in the home laundry. As was shown in Chapter I, residential water conservation is becoming increasingly necessary. The type of research design, sample, materials, data collection and the data analysis used in the study are described in this chapter.

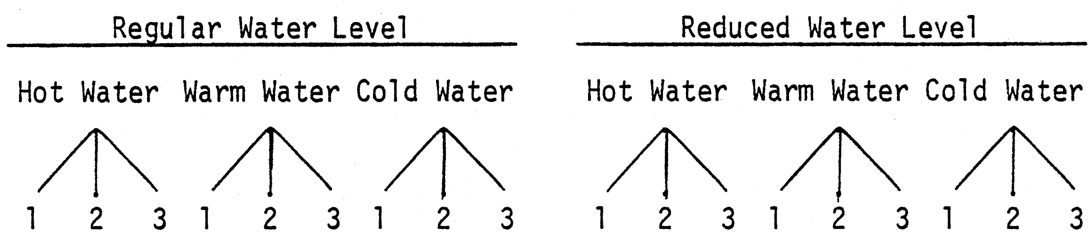
Type of Research Design

The type of research design selected for use in this research study was experimental. Mason and Bramble (1978, p. 43) stated that experimental research "involves systematic manipulation of experimental conditions in which extraneous influences are controlled or eliminated." Mason and Bramble further stated that by isolation and study of the variables, the effects of one variable upon another can be discerned.

Compton and Hall (1972, p. 95) in agreement with Mason and Bramble stated that:

> . . . the experimental method is the application of logic or reason to observations made in a completely controlled situation where one variable alone is permitted free play. Control can be achieved either by: (1) holding constant the variables that are extraneous to your hypothesis to prevent them from changing; or (2) deliberately causing a variable that is pertinent to your hypothesis to change in a prescribed manner.

The present study controlled the experimental variables in both of the above described methods. The load composition, wash cycles, amount and placement of dirt, and washing procedure were kept constant. The water level, water temperature and detergent type were manipulated in a prescribed manner. The treatment design is presented in the following schematic diagram (Figure 1). There were a total of eighteen combinations of treatment variables. There were twelve replications of each combination.



1 Anionic detergent
2 Nonionic detergent
3 Cold water anionic detergent

Figure 1. Treatment Design of Experimental Variables in Laundry Procedures

Sample

The sample for the study consisted of four 3x3½ inch samples of soil cloth placed in each load of clothes. The soil on the soil cloth was a combination of particulate and oily soil impregnated on a 65% polyester/35% cotton blend shirting with a permanent press finish. The soil cloth was obtained from Test Fabrics of New Jersey.

In preparation for the washing procedure, the soil cloth was cut so that each piece contained a 3x3½ inch soiled area. The raw edges of the soil cloth samples were finished with a machine zig zag stitch to prevent excessive fraying and linting. Four soil cloth samples were added to each laundry load prior to the washing cycle. One sample was attached with a safety pin to the collarstand of each of the three men's white dress shirts. The fourth sample was attached to the middle of the bottom hem of the flat bed sheet. The samples were attached so that the soiled side faced away from the base piece of laundry.

Equipment and Supplies Used in Study

The equipment and supplies used to complete this study are described in this section. Equipment and supplies used included automatic clothes washers, clothes dryers, water heaters, a reflectometer, water, detergent and laundry load.

Washers

The washers used in the study were two identical Maytag Model A310 agitator automatic washers. Water temperature was the only part of the washing procedure that was manually controlled. The temperature of the water was controlled by the researcher as the machine filled. The automatic washing cycle set by the washer manufacturer for permanent press and either large or medium load size setting was used. The water temperature for the hot water was 130°±5°F, the temperature for the warm water loads was 100°±5°F, and the temperature for the cold water loads was 80°±5°F.

The cycle chosen for all the washings was one with normal agitation and extraction rate with a cold rinse. The water levels were set at either the large or the medium water settings. According to the manual the large setting used 16 gallons per agitation cycle and 36 gallons for a complete washing cycle. The medium setting used 12.5 gallons for the agitation cycle and 29 gallons for a complete washing cycle. The time set for agitation was the maximum as indicated on the timer dial for permanent press; this set the machine for a 12 minute wash agitation with a 3 minute deep rinse. The total time of the cycle was 35 minutes. All of the wash loads were rinsed in cold water.

Dryers

The fabrics in the study were mechanically dried in two identical electric Maytag Model DE410 dryers. The cycle chosen was that of time dry, at the regular heat setting. The dryer timer was set for 30 minutes of heat and tumbling. The laundry load was removed from the dryer as soon as the timer sounded. The soil cloth samples were removed and coded with the load code and the wash number. The remainder of the load was then folded and stacked on shelves for the next washing procedure.

Water Heaters

Two water heaters were used in this study. Each water heater serviced one of the washing machines. One of the water heaters was a Ruddglass Pacemaker Model RP40S-2 with a 40 gallon capacity. The other was a Ruddglass Pacemaker Model RP40-2 with a 40 gallon capacity. Both were set to heat and keep their water at 150°F. The water heaters were set higher than the hot water temperature to be used in this study. The difference in temperature is to compensate for the cooling of the water while in transit between the water heater and the washing machine. This allowed the researcher to keep the hot water in the washing machines at the prescribed temperatures.

Reflectometer

A Photovolt Reflectometer base unit Model 670 was used with a search unit Model 4-570-01 to obtain the reflectance readings used in the study. The grey standard for 45°, 0° Directional Reflectance with a tri-green filter reading of 50.0 was used to standardize the reflectometer readings. The reflectometer was rechecked against the standard after each reading to see that the meter had not drifted. Reflectance readings are an indirect measure of the amount of soil removal. Higher values indicate more light reflectance, and therefore greater soil removal.

After completion of the washing procedure the soil cloth samples were collected and coded. Each sample then had its reflectance measured in two places and the readings were recorded.

Water

Tap water supplied by the city of Stillwater, Oklahoma was used. It was not altered in any way except for heating to a temperature of 150°F in the above described water heaters for the washing procedure.

Detergent

Three types of commercially available detergents were used in the study. Since the objective of the study involves the use of a home laundry setting, detergents readily available for home use were used. The detergents selected for this study were 1) anionic, 2) nonionic and 3) cold water anionic. The amount of detergent used was that amount recommended by its manufacturer. The detergent was added as the washing machine filled to insure that the detergent was completely dissolved before the load was placed in the machine.

Laundry Load

The items used in the laundry load functioned as ballast, to fill in the load to more closely simulate a home laundry setting. The laundry consisted of items which would be representative of a family's washbasket, and weighed approximately 12 pounds. It contained one pair of full size bed sheets, two pillow cases, two bath towels, two washcloths, three pair of men's jockey shorts, three men's tee-shirts, and three short sleeved dress shirts. All of the items were white and the fiber contents were blends of cotton and polyester. All of the items were obtained from the same source.

The laundry load was coded and marked with a laundry marking pen. The coding system indicated the water level, replication number, water temperature and detergent type. The first character indicated the water level, with either an R for regular or an L for reduced level. The second character indicated the replication number 1 through 3. The third character indicated the water temperature; either H for hot water, W for warm water, or C for cold water. The fourth character indicated the detergent type; 1 for anionic, 2 for nonionic and 3 for cold water anionic.

There were a total of 18 combinations of experimental variables. There were 12 replications of each combination.

Washing Procedure and Data Collection

Before each washing procedure was begun, the soil cloth samples and laundry loads underwent preliminary preparation as previous described. The washing machines were filled with the prescribed amount and temperature of water for the load to be washed. The recommended amount of detergent was added as the washing machine filled to insure that the detergent was completely dissolved before the laundry load was placed in the machine.

The laundry load was added to the washing machine when the water fill period ended and before the agitation began. A final check of the water temperature was made and recorded. The specific washing machine used was also recorded. The laundry loads were washed in both machines an equal number of times to compensate for any differences between the machines.

When the washing cycle was completed, the laundry load was transferred to the dryer. The laundry load was dried under conditions previously described. The laundry loads also alternated between the two dryers to compensate for any differences between the dryers.

After the laundry load was removed from the dryer, the four soil cloth samples were removed from the laundry load base items. The laundry load was then readied for another washing cycle with new soil cloth samples.

The samples were then evaluated with the Reflectometer. The readings were taken using the tri-green filter, standardized with the grey standard. The samples were placed on the grey standard while the readings were taken and recorded.

Data Analysis

Mean values for each treatment were calculated after laundering by adding all the reflectance values and dividing by the total number of observations. An analysis of variance model was used to determine whether significant differences between the means were present. The analysis of variance model included the variables of water level, water temperature, and detergent type and the interactions among those variables. There were two two-way interactions and one three-way interaction between the variables included in the statement of the null hypothesis of the study. The interactions are listed as follows:

Water Level X Water Temperature,

Water Level X Detergent Type,

Water Temperature X Detergent Type,

Water Level X Water Temperature X Detergent Type.

CHAPTER IV

RESULTS

The study was designed to determine the effectiveness of a reduced water level on the removal of soil from clothes in a home laundry simulation. The null hypothesis formulated for this study was as follows:

H_1: There will be no significant difference between the amount of soil removed in a reduced water level and in a standard water level using (a) three different detergents, and (b) three different water temperatures.

Mean values for each treatment were calculated after laundering by adding all the reflectance values and dividing by the total number of readings. Reflectance readings are an indirect measure of the amount of soil removed. Higher values indicate more light reflectance and therefore greater soil removal.

Analysis of variance (ANOVA) was used to determine whether significant differences between the means were present. The ANOVA model includes the variables of water level, water temperature, detergent type and the interactions among these variables. The F-scores were obtained by dividing the mean squares of the treatments by the residual mean square. A .05 level of significance was used to accept or reject null hypothesis. Table I shows the ANOVA table for the study.

The ANOVA indicated that water level alone was not a significant

TABLE I

ANALYSIS OF VARIANCE OF INTERACTIONS AMONG
VARIABLES ON SOIL REMOVAL

Source	dF	Sum of Square	Mean Square	F-Score	Probability
Water Level	1	7.5933	7.59327	0.32858	0.5742
Water Temperature	2	164.3344	82.16719	3.55557	0.0295*
Detergent Type	2	4973.3381	2486.69905	107.60425	0.0001**
Water Level X Water Temperature	2	54.5531	27.27656	1.18032	0.3092
Water Level X Detergent Type	2	42.5953	21.29764	0.92160	0.5980
Water Temperature X Detergent Type	4	522.0997	130.52492	5.64813	0.0005**
Water Level X Water Temperature X Detergent Type	4	46.9222	11.73056	0.50761	0.7333

*Significant at the .05 level

**Significant at the .0005 level

factor in soil removal. Water level with water temperature and/or detergent did not produce any means that were significantly different from each other.

The variable of detergent type produced significant differences in mean scores ($p<.0005$). Water temperature alone also produced significant differences ($p<.05$). The treatment combination of water temperature and detergent produced significant differences ($p<.0005$). Since these variables and combination of the variables were not part of the main focus of this study, they will not be discussed further.

The results of the analysis of variance indicated that factors other than water level were responsible for significant differences in soil removal. On the basis of the ANOVA model, the null hypothesis as stated above was accepted. The means of all variables, with significant and not significant differences will be discussed below.

Mean values for the effect of water level alone were computed and are shown in Table II. The mean value for the standard water level was lower than the mean value for the reduced water level, although the ANOVA revealed the difference was not significant.

Mean values for the effect of water level and water temperature were computed and are shown in Table III. The treatment combination of the standard water level and cold water produced the lowest mean value. The highest mean value was for the treatment combination of reduced water and warm water. For both cold and warm water, the mean values were higher when combined with the reduced water level. The differences, however, were not statistically significant, as shown in Table I.

TABLE II

MEAN VALUES FOR THE EFFECT OF WATER LEVEL
ON SOIL REMOVAL
(n=216)

Source	Mean Value
Reduced Water Level	32.3280952
Standard Water Level	32.1935561

TABLE III

MEAN VALUES FOR THE EFFECT OF WATER LEVEL
X WATER TEMPERATURE ON SOIL REMOVAL
(n=72)

Water Level	Water Temperature	Mean Value
Reduced	Cold	32.1253571
Reduced	Warm	32.5443662
Reduced	Hot	32.3112319
Standard	Cold	31.5160714
Standard	Warm	32.4901460
Standard	Hot	32.5753521

Mean values for the effect of water level and detergent type were computed and are shown in Table IV. The lowest mean value in this category was for the treatment combination of the anionic detergent and the standard water level. The cold water anionic detergent combined with the standard water level produced the highest mean value. The reduced water level in combination with the anionic and the nonionic detergent had higher mean values than the standard water level with the same detergents. These differences in mean values are not statistically significant.

TABLE IV

MEAN VALUES FOR THE EFFECT OF WATER LEVEL X DETERGENT TYPE ON SOIL REMOVAL (n=72)

Water Level	Detergent Type	Mean Value
Reduced	Anionic	29.8125000
Reduced	Nonionic	33.4353571
Reduced	Cold Water Anionic	33.6274306
Standard	Anionic	29.7703704
Standard	Nonionic	32.8675000
Standard	Cold Water Anionic	33.8100694

Mean values for water level, water temperature and detergent type were computed and are shown in Table V. The lowest mean value was for the treatment combination of the anionic detergent and a cold standard water level. The combination of the cold water anionic detergent with a warm standard water level produced the highest mean value. The anionic detergent produced the lowest mean values when interacted with any of the combinations of water level and water temperature. The nonionic detergent produced mean values that were consistently higher than the anionic detergent when interacted with any of the combinations of water level and water temperature. The differences, when analyzed, did not prove to be significant.

TABLE V

MEAN VALUES FOR THE EFFECT OF WATER LEVEL X WATER TEMPERATURE X DETERGENT TYPE ON SOIL REMOVAL (n=24)

Water Level	Water Temperature	Detergent Type	Mean Value
Reduced	Cold	Anionic	29.6454545
Reduced	Cold	Nonionic	32.5010417
Reduced	Cold	Cold Water Anionic	34.0229167
Reduced	Warm	Anionic	29.7119565
Reduced	Warm	Nonionic	33.3791667
Reduced	Warm	Cold Water Anionic	34.4239583
Reduced	Hot	Anionic	30.0728261
Reduced	Hot	Nonionic	34.5159091
Reduced	Hot	Cold Water Anionic	32.4554167
Standard	Cold	Anionic	28.9431818
Standard	Cold	Nonionic	31.8968750
Standard	Cold	Cold Water Anionic	33.4937500
Standard	Warm	Anionic	29.6388889
Standard	Warm	Nonionic	33.1090909
Standard	Warm	Cold Water Anionic	34.5958333
Standard	Hot	Anionic	30.6902174
Standard	Hot	Nonionic	33.6166667
Standard	Hot	Cold Water Anionic	33.3406250

As indicated earlier, of the differences in the mean values for all the variables and combinations of variables, only three were of statistical significance. The variable of water temperature produced significant differences in mean values at the .05 level. At the .0005 level of significance, detergent type, and the treatment combination of water temperature and detergent type had significant differences in mean values. The major focus of this study, water level, was not a significant factor by itself or in combination with the other variables. The null hypothesis, as stated earlier, was accepted. According to the results of this study there was no significant difference between the amount of soil removed in a reduced water level and in a standard water level, with the added variables of water temperature and detergent type.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Conservation and thoughtful usage of our natural resources has become a topic of national concern. The American public has been made aware of the limited nature of the supply of both energy and water. This concern is reflected in this study and its focus on developing a satisfactory home laundering process using a reduced amount of water.

Three objectives were identified for this study. These objectives were:

1. To compare the effect of a reduced water level on soil removal with the soil removal of a standard water level.

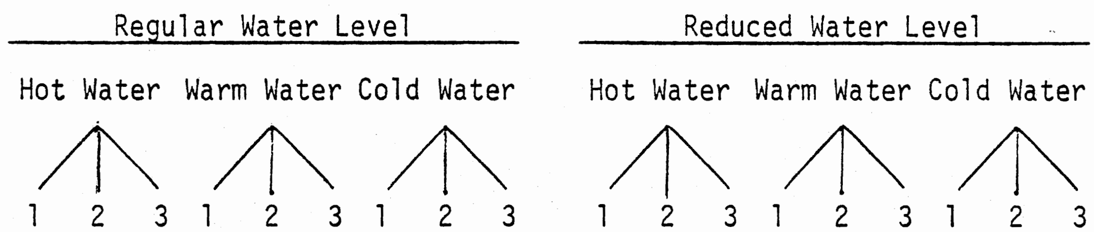
2. To determine whether detergent composition affects soil removal at specified water levels.

3. To determine whether water temperature affects soil removal at specified water levels.

The null hypothesis tested in this study was:

H_1: There will be no significant difference between the amount of soil removed in a reduced water level and in a standard water level using (a) three different detergents, and (b) three different water temperatures.

An experimental research design was used in this study. The variables of placement of standard soil cloth, laundering procedures and load composition were kept constant. The variables of water level, water temperature and detergent type were manipulated in a prescribed manner. The 18 combinations of experimental variables are shown below.



1 Anionic detergent
2 Nonionic detergent
3 Cold water anionic detergent

Figure 2. Treatment Design of Experimental Variables in Laundry Procedures

Mean values for each treatment were calculated after laundering by adding all the reflectance values and dividing by the total number of readings. An analysis of variance model was used to determine whether significant differences between the means were present. The model indicated that water level alone was not a significant factor in soil removal. The mean values for the standard water level were lower than those of the reduced water level, but the difference was not large enough to be significant. Therefore the null hypothesis has been accepted. There was no significant difference in the amount of soil removed in reduced or standard water levels.

Based on the findings of this study, it may be possible to use a reduced amount of water in the home laundry. Further study, taking into account other factors would be needed before the use of a reduced water level is promoted. This study controlled carefully a number of variables that, under normal circumstances, are not able to be manipulated. Bowers and Chantrey (1969) recommended that laboratory studies of soil and soil removal be interpreted with great care. Soil and soil removal are complex phenomena and controlled experiments such as this can indicate possible solutions to laundry problems or avenues of further study. An actual wear study using many of the procedures used in this study would provide wash loads of various amounts and types of soil. This would yield results that would be more transferable to actual situations.

The other variables involved in this study would also need to be explored further. The type and amount of detergent used is a major factor in soil removal. Grindstaff, Patterson and Billica (1970) stated that detergent concentration was an important part of soil removal. The detergent concentration varied with the amount of water used in this study. The effect of the ratio of detergent to water in a reduced water setting may vary from that of a standard water level and needs to be investigated.

Factors other than those controlled in this study are also present in the home laundry situation. The reduced water volume may lead to more abrasion between the articles in the wash load and shorten the wear life of those articles. The savings of water may need to be balanced with the wear on the fabric washed with less water.

The reduced amount of water may also alter the effectiveness of permanent press articles. The items in each load may not be able to move as freely through the wash solution and may become twisted and wrinkled. Excessive wrinkling and the need to iron may well offset the advantages of water saving. The results of the study were promising but the concept needs further investigation before it is put into widespread use.

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