1 of 3

February 22, 1973

To the Graduate Council:

I am submitting herewith a thesis written by Jeanne Dupuy Thompson entitled "Removal of Surfactant From Fabric Laundered in Automatic Clothes Washers in Relation to Tub Type and Rinsing Methods and Other Variables." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Home Management, Equipment, and Family Economics.

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REMOVAL OF SURFACTANT FROM FABRIC LAUNDERED IN AUTOMATIC CLOTHES WASHERS IN RELATION TO TUB TYPE AND RINSING METHODS AND OTHER VARIABLES

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Jeanne Dupuy Thompson

March 1973

ACKNOWLEDGMENTS

The writer wishes to express her sincere gratitude to Miss Lyle Mamer, Associate Professor of Home Management, Equipment, and Family Economics, for her guidance in designing the experiment and in setting up the testing equipment. Special thanks is given to Dr. Peggy Berger, Assistant Professor of Home Management, Equipment, and Family Economics for her cheerful counsel; and to Dr. John Smith, Professor of Nutrition, who patiently guided her through the chemical research.

Appreciation is also expressed to other members of the Nutrition Department who gave assistance, and to those members of The University of Tennessee Maintenance Department who assisted in moving, assembling, and servicing equipment.

A special note of gratitude is extended to her friends for their sincere interest. Above all, she wishes to thank her family, especially Marjie and Jeanne, for their loving encouragement in this pursuit.

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ABSTRACT

The purpose of this study was to evaluate the rinsing efficiency of three solid tub and three perforated tub clothes washers and the method of rinsing utilized by each type to determine if one were more effective than the other in removing surfactant from a laundry load. The variables considered were the amount of surfactant removed from the load after rinsing, the temperature of the water, the water and energy consumption, and the water hardness.

Factors which were controlled were the type and amount of detergent used, the voltage of the circuit, and the wash agitation time.

It was hypothesized that on the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of surfactant removed by the method of rinsing utilized and that this difference is influenced by the temperature of the water, the amount of water and energy used, and the hardness of the water. It was also hypothesized that there was a significant difference in the rinsing efficiency among the washers in the two types. All six hypotheses were rejected after data were analyzed by analysis of variance or analysis of covariance.

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CHAPTER I

INTRODUCTION

A question asked of home economists concerns the effectiveness of the rinsing actions of different automatic clothes washers. This study was undertaken to try to answer this question.

According to Merchandise Week, there were approximately 65,600,000 domestic and farm electric customers in the United States as of December 31, 1971 (6, p. 66). Of the households having electricity, over 94 percent owned clothes washers (6, p. 66). This source also noted that 4,609,000 washers were shipped by manufacturers during 1971 (6, p. 61). Of the number sold to consumers, 68 percent were replacement sales (6, p. 61). These figures would seem to indicate that the homemaker intends to continue doing her own laundry. Information about the types of rinses built into today's automatic washers should be available to her so that she can choose a washer that best meets her needs.

In the spring of 1971, Consumers' Research tested several washers to determine their cleansing potential. They found that all models tested left much to be desired in regard to rinsing (3, p. 27). Today's clothes washers are equipped with one of or a combination of three rinsing actions. These are:

(1) a spray or flush rinse, (2) an overflow or flotation rinse used with or without agitation, and (3) a deep agitating rinse. The spray rinse is usually incorporated with one of the other two rinses during the selected portion of the cycle. Manufacturers who utilize the overflow rinse, which is found in solid tub washers, feel this rinsing method is best because the surfactant and soil floats to the surface and is forced out over the top of the tub, then pumped away. The perforated tub uses the deep agitating rinse in which the water is spun out through the holes of the tub. In this method the clothes may trap some of the residue.

I. STATEMENT OF THE PROBLEM

The purposes of this study were to investigate the differences between automatic washers having solid tubs and those having perforated tubs, when operated on a hot wash, warm rinse setting, in relation to the (1) amount of surfactant removed, (2) temperature of the wash and rinse water, (3) volume of water used, (4) electrical energy consumed, and (5) water hardness. The subjects of the study were three solid tub automatic washers utilizing the overflow method of rinsing and three perforated tub washers with the flush and deep agitated method of rinsing. All washers, regardless of size, were operated at the normal load setting.

II. HYPOTHESES

The following hypotheses were tested:

1. On the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of surfactant removed by the method of rinsing utilized.

2. On the hot wash, warm rinse setting, there is a significant difference in the amount of surfactant removed by the method of rinsing utilized among the washers within types.

3. On the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of surfactant removed by the method of rinsing utilized in relation to the temperature of the water during the laundry cycle.

4. On the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of surfactant removed by the method of rinsing utilized in relation to the amount of water consumed during a laundry cycle.

5. On the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of surfactant removed by the method of rinsing utilized in relation to the amount of electrical energy consumed during a laundry cycle.

6. On the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of surfactant removed by the method of rinsing utilized in relation to the hardness of the water used.

III. DEFINITION OF TERMS

The following terms and their definitions are based on terminology recommended by the Association of Home Appliance Manufacturers (10).

1. An all-purpose detergent is a heavy duty, built laundry product used to remove soil from all fabrics in the family laundry. It contains organic active ingredients, moderately alkaline builders, brighteners, anti-redeposition agents, and corrosion inhibitors. It may include bluing, bleach, fabric softeners, or other special ingredients.

2. A cycle consists of the several operations the washer performs from the time it is started until it shuts off. A part of a complete cycle is referred to as a portion, such as the rinse portion of a cycle.

3. A deep agitating rinse occurs when the clothes are mechanically circulated through a full washer tub of clean water.

4. An overflow rinse results from the filling of the washer tub with clean water until it runs over the top,

taking with it the lint and insoluble material. It may be accompanied with or without agitation.

5. A spray rinse is the process of introducing clean water into the tub during the spin cycles causing the detergent suds to be removed by a flushing action.

6. A surfactant is the principal ingredient in a synthetic detergent. It allows the wash water to wet the fabric thoroughly, it removes the soil, and it aids in suspending and emulsifying the soil.

CHAPTER II

REVIEW OF LITERATURE

I. THE WASHER

The advent of the automatic washer was hailed as an achievement by Goodhue (9) for it would allow continuous use of clean water which would give better removal of soil. The importance of good rinsing has been investigated less than any other phase of the laundry cycle and yet its significance has often been cited. In 1954, Weaver (22, p. 7) found that washers having two deep rinses tended to keep clothing whiter than those having only one deep rinse and spray rinses. Ehrenkranz (7, p. 47) determined the maximum amount of certain detergents to be used in laundering which would be completely rinsed out of a load during one laundry cycle. During a test period of several weeks, she laundered soiled cotton linens in the predetermined amounts of detergents, using three different household washers. She obtained only a slight buildup of detergent, but the clothing did not appear clean.

Limited information is supplied by the manufacturer in his descriptive literature in regard to the kinds of rinses built into the washer, the number of rinses, and the length of time the laundry is rinsed. The specification sheets for

the 12 manufacturers included in a 1972 book (1) gave few details as to the rinsing actions their products provide. Among the washers used in this experimental study, only one manufacturer supplied adequate information for the consumer in regard to the rinsing actions. A Consumer Bulletin report of 1971 (3, p. 8) stated that two machines with overflow rinses were above average in dirt removal effectiveness, but they did not determine what effect the rinsing method used in the machines had on their ability to remove dirt from fabrics. Another washer having a perforated tub, whose maker claimed it had a special type of rinsing action in which the soil and detergent film were forced up over the top of the clothes and out the holes, was below average in soil removal ability.

II. LOAD

The weight of the load and the size of the articles comprising the load affect the circulation of the water through the articles and the movement of the articles through the water. Potter (14, p. 16) reported that both the weight of the load and the size of the individual pieces had an effect on agitation. Weaver (22, p. 33) found that loads consisting of all small items moved more freely than loads made up of all large items. She further determined the satisfaction of the use of a load of combined large and small items. Her investigation revealed that filling the machine to capacity

by weight as recommended by the manufacturer as a rule did not allow for free movement of the clothing. Ross et al. (16, p. 13) obtained better results in their study when the weight of the load was decreased from that stated as the rated capacity. The Consumer Bulletin report (3, pp. 10-12) showed that of those washers found acceptable by their standards, only about one half were efficient at the manufacturer's recommended load.

Load content in research has consisted both of stuffers and actual articles of family clothing. Snell (19, p. 485) proposed that conditions of testing be as near an "at home" situation as possible, including the use of clothing worn by family members. The American Society for Testing and Materials (13, p. 27) specified that a test load representative of a family laundry bundle be used. They determined that a median weight load for most top loading automatics was six pounds. Consumers' Research did their testing with loads consisting of mixed cotton items representative of a family laundry load (3, p. 10). The American Home Appliance Manufacturers (AHAM), in their published An American National Standard Performance Evaluation Procedure for Household Washers (2, p. 6) suggested a standard mixed cotton test load typical of a family's normal cotton load. They listed items of linen and clothing and their weights that would probably comprise such a load. They did, however, provide specifications for a stuffer load.

In placing the load into the washer, Goodhue (9) suggested arranging the pieces loosely in the tub until it was about seven-eighths full from the load line. AHAM (2, p. 8) specified that large items be placed in the washer first with smaller items dropped on top of them.

III. WATER

The hardness of the water and its temperature, as well as the amount of water used throughout the laundry cycle, are important interacting factors with the rinsing mechanism of the washer in removing the surfactant. The hardness of the water is primarily calcium and magnesium ions. Hardness measurements are usually expressed in terms of equivalent calcium carbonate. The units used are either parts per million or grains per U.S. gallon. Loeb (11) reported that even using the heavy duty detergents containing the phosphates which help to overcome the hardness problems of water, the processes of soil removal, redeposition, and rinsability were adversely affected by water hardness of 6 to 12 grains per gallon. Findings indicated that about 80 percent of the water supplied to all homes in the United States fell into this range.

In the USDA Bulletin No. 1497 (12, p. 29), it was stated that rinsing should be done in hot, clear, soft water for detergent left in clothing caused the fabric to yellow and

the fibers to be weakened. Williams reported a significant difference in the effectiveness of two rinses with hard water as compared with one, while she obtained no significant difference between one or two rinses with soft water (23, p. 48). Beale (4, p. 35) found that two hard water rinses were only a little less effective than one soft rinse and that two soft rinses were more effective than either one soft rinse or two hard rinses. In an Iowa State University Bulletin (5, p. 11), it was recommended that a nonprecipitating softener be added in the first rinse, and if excessive sudsing was still present, a second softened rinse should be used.

The temperature of the rinse water has been a variable in other investigations. Faragher (8, p. 644) stated that rinse water should be hot. A 1931 study by Roberts (15, p. 20) indicated that the first rinse water should be the same temperature as the washing water for if the rinse were of a lower temperature the fibers would contract and the soil might be trapped between the threads and would be harder to remove. Synder and Brunig (20, p. 31) also felt that a rinse whose temperature was more than 20 degrees below that of the washing water would cause the fabric to contract and hold the dirt and surfactant. Potter (14, p. 25) suggested that the temperature of the first rinse be near the original wash water. Williams (23, p. 49), however, reported she found no significant difference between a warm rinse, 100°F (37.78°C), and a hot rinse,

140°F (60.0°C), in hard or soft water. Today, many of the automatic washers have the control of the wash and rinse temperatures built in. Most provide for a hot water wash and a warm water rinse at the normal setting (1). The recommendations for temperature of the water included in AHAM HLW-1 (2, p. 8) are 140°F (60.0°C) for washing and 100°F (37.78°C) for rinsing. This is the approximate temperature of the water delivered to home washers when the water heater is set on high.

There was no mention made of a definite amount of water that would give the most surfactant-free laundry. In several of the studies cited previously, mention is made of the comparison of one or two rinses (23, p. 48; 3, p. 37; 5, p. 11; 15, p. 20; 14, p. 25). And another study suggested that "plenty" of water be used (12, p. 29). In her study, Weaver advanced the theory that the more water used in rinsing the less the amount of soiled wash water that would be retained by the load after extraction (22, p. 31).

IV. SURFACTANT

The laundry product most used today is an anionic, heavy-duty, built detergent. The basic ingredient is a surface active agent which is referred to as a surfactant (17). The surfactant is the main soil removing agent of the detergent but it cannot clean cottons and other fabrics well

unless conditions of the washing water are right. To help create the proper wash water conditions of softness and pH, builders are added to the surfactant. The most widely used builder is some form of phosphate. In addition, other ingredients such as suds inhibitors, suds stabilizers, corrosion inhibitors, anti-redeposition agents, brighteners, bleaches, bluing ingredients, bacteriostats, and perfumes may be added (10). A typical heavy duty detergent may contain 20 to 30 percent surfactant, 30 to 50 percent phosphate builders, and the remainder of the product consist of the neutral builders (18).

The recommendations of a clothes washer manufacturer in regard to detergent amounts are generally to use the quantity recommended by the manufacturer of the detergent. Several manufacturers of washers have packed a well-known detergent in their new machines. This detergent manufacturer recommended the use of from 3/4 to 1 1/2 cups of detergent but the exact amount should be determined by the homemaker in relation to the size of the load she is laundering, the hardness of the water, and the soil in the clothes. The detergent manufacturer further recommends that additional detergent be added to counteract hardness of water because the detergent has a built-in softener (21). This increases the amount of active ingredient present which may not be needed to cleanse the clothes but must be removed by the washer during the rinse periods. Most

homemakers do not treat the rinse waters to duplicate the conditions of the wash water in regard to softness but rinse the laundry in water as it comes from the tap.

CHAPTER III

COLLECTION OF DATA

I. DESIGN OF EXPERIMENT

Basis for the experiment was An American National Standard Performance Evaluation Procedure for Household Washers (AHAM HLW-1) (2) which is approved by the American National Standards Institute and officially numbered Z224.1-1971. Although this Standard was designed to evaluate new machines on a onetime basis, it was determined that with modifications the Rinsing Effectiveness portion of the Standard could be used to test surfactant buildup over a period of several launderings.

All laundry was done in six different automatic washers, three with solid tubs and three with perforated tubs, which were installed in the equipment laboratory at The University of Tennessee, Knoxville. The washers were identified by numbers one through six for ease in tabulating results.

As the experiment was constructed to simulate home conditions in laundering, no effort was made to control the hardness of the water, the temperature of the water, or the quantity of water used during a cycle. Repetitive cycles for each washer were carried out consecutively. Each washer was

operated on its normal load cycle setting using a hot water wash and a warm water rinse. Agitation time during the wash portion of the cycle was maintained at ten minutes ± one minute. The remaining portions of the laundry cycle were uncontrolled by the experimenter.

Selection of the items used in a load was based on AHAM's suggested list of items (2, p. 6). Identical loads of new, desized, all cotton linens were used in each machine. Five sets of nine muslin samples were attached to a load. The surfactant buildup in the samples was extracted. This extraction was treated then measured for absorbance or optical density using a spectrophotometer.

Factors which were controlled were the type and amount of detergent used, the voltage of the circuit, and the wash agitation time.

Data recorded for each load were the hardness of water in grains per gallon, temperature of wash and rinse water in degrees Fahrenheit, water consumption in eighths of a gallon, and energy consumption in watt-hours.

Data compiled from processing the samples were the weight in grams of the muslin samples and absorbance.

II. PRETESTING

Preliminary testing was done to familiarize the researcher with AHAM Standard HLW-1 (2) and to formulate changes to be

made to fit the design of the experiment. This included (1) determining the composition and size of the wash load, (2) selecting the fabric and the size of the samples to be tested, (3) setting a standard of surfactant saturation to which rinse concentration samples could be compared, and (4) establishing a conditioning procedure for the washers and the loads. Equipment to be used in obtaining data was studied and a method of recording this information was set up.

III. TEST PROCEDURE

Laundry Load

The fabric load for each washer consisted of new 100 percent cotton linens and weighed approximately six pounds. The identical loads assembled consisted of the following items:

2 - bath towels, terry, 24 inches by 42 inches,

2 - hand towels, terry, 16 inches by 25 inches,

4 - washcloths, terry, 12 inches by 12 inches,

2 - sheets, percale, 72 inches by 108 inches,

2 - pillowcases, percale, 36 inches by 42 inches,

3 - dish towels, terry, 14 inches by 22 inches,

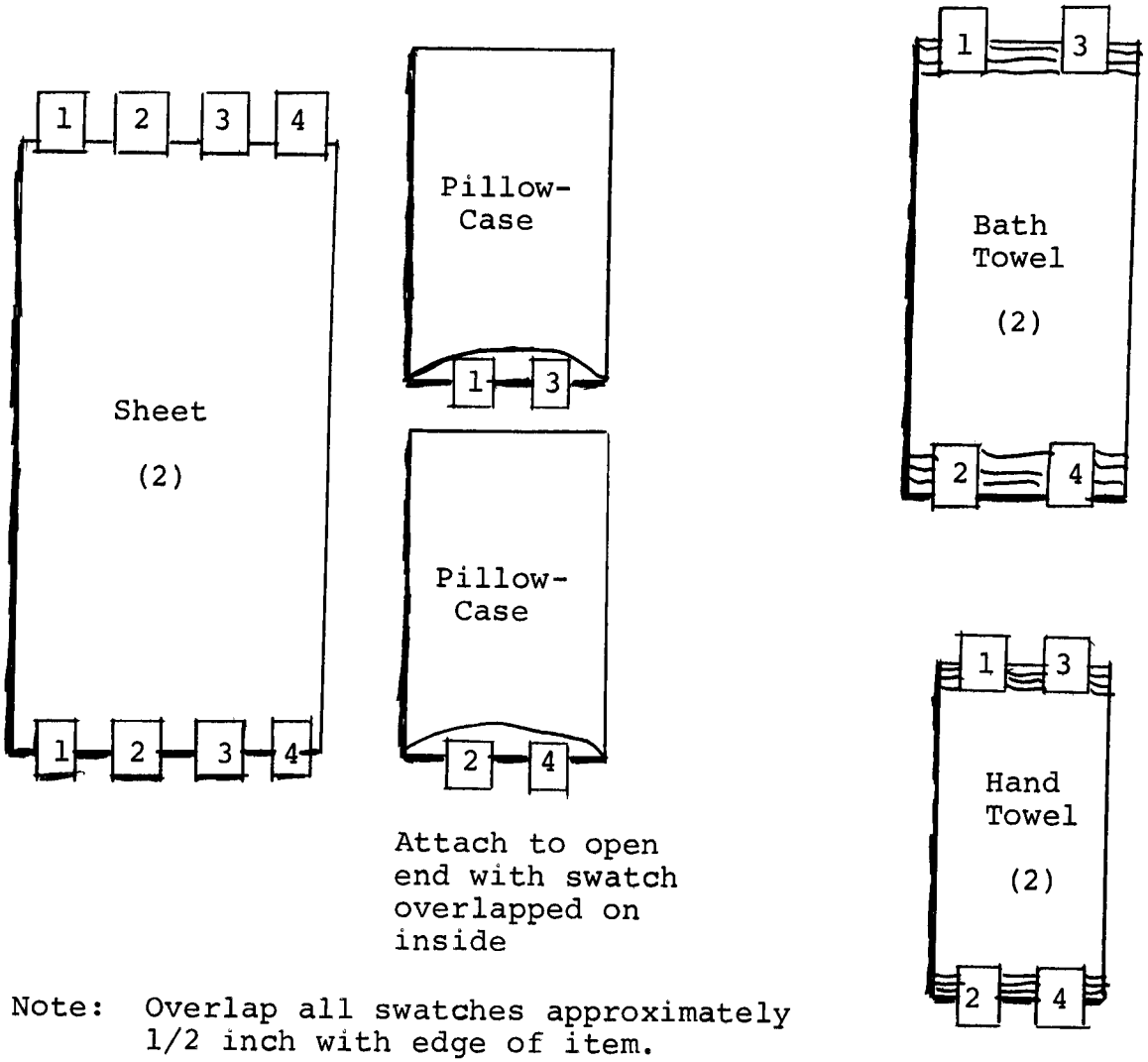
2 - pot holders, terry, 6 inches by 6 inches.

Fabric Samples

Fabric selected to be used for extraction samples, wash concentration samples (WCS) and rinse concentration samples (RCS), was 100 percent cotton eighty square muslin. Samples

were torn to a size of five inches by six inches. Each was double stitched along the raw edges. A set of samples consisting of nine squares was provided for WCS. Five sets of nine samples each were provided for each washer. These RCS sets were numbered one through five. Four sets were attached to the major pieces of the load as shown in Figure 1. This was done with a sewing machine using the basting stitch. The samples were attached between the second and third load-conditioning cycles. The fifth set was attached to the smaller items in the load, one to each piece, to provide extra samples if needed. The AHAM test extracted surfactant from a total of 90 square inches of RCS in three runs, 30 square inches per run. A complete wash cycle constituted a run. The three runs provided the data for the formula for calculating percent surfactant removed. This experiment provided the data by extracting surfactant from 90 square inches of RCS using three Soxhlets, each holding 30 square inches of fabric.

Additional muslin squares were made to be used to replace the weight lost when a set of samples was removed. These were not attached to the load but were assembled in groups of four or five by tacking them together in the center of the squares. These were added to the load in the machine.



Note: Overlap all swatches approximately 1/2 inch with edge of item.

Figure 1. Sample attachment to load.

SLS Calibration Curve

The Rinsing Effectiveness Test of AHAM Standard HLW-1 (2, p. 20) was designed to evaluate the rinsing effectiveness of household washers.

> This procedure is based on the assumption that the efficiency of the rinsing sequence is related to the amount of organic surfactant remaining in the fabric load after completion of the cycle as related to the amount of surfactant remaining in the load at the end of the wash portion of the cycle (2, p. 23).

Prior to beginning the actual testing in the washers, a calibration curve was prepared for sodium lauryl sulfate (SLS) at a concentration of 20 parts per million or less according to instructions in AHAM Standard HLW-1 (2, pp. 20-21), steps 5.4.1.1. through 5.4.1.12. This provided a norm against which surfactant buildup in WCS and RCS could be measured. Figure 2 shows this calibration curve.

Standard of Wash Concentration Samples

In the AHAM test, WCS were obtained by immersing cloth samples in the wash water for 15 ± 2 seconds then allowing them to drip dry. In this experiment, WCS were obtained in the following way:

1. Nine muslin samples were desized by rinsing them three times in one gallon of hot clean tap water to which was added one-fourth cup of packaged softener of the sodium hexamethaphosphate-type to create excessively soft water. During

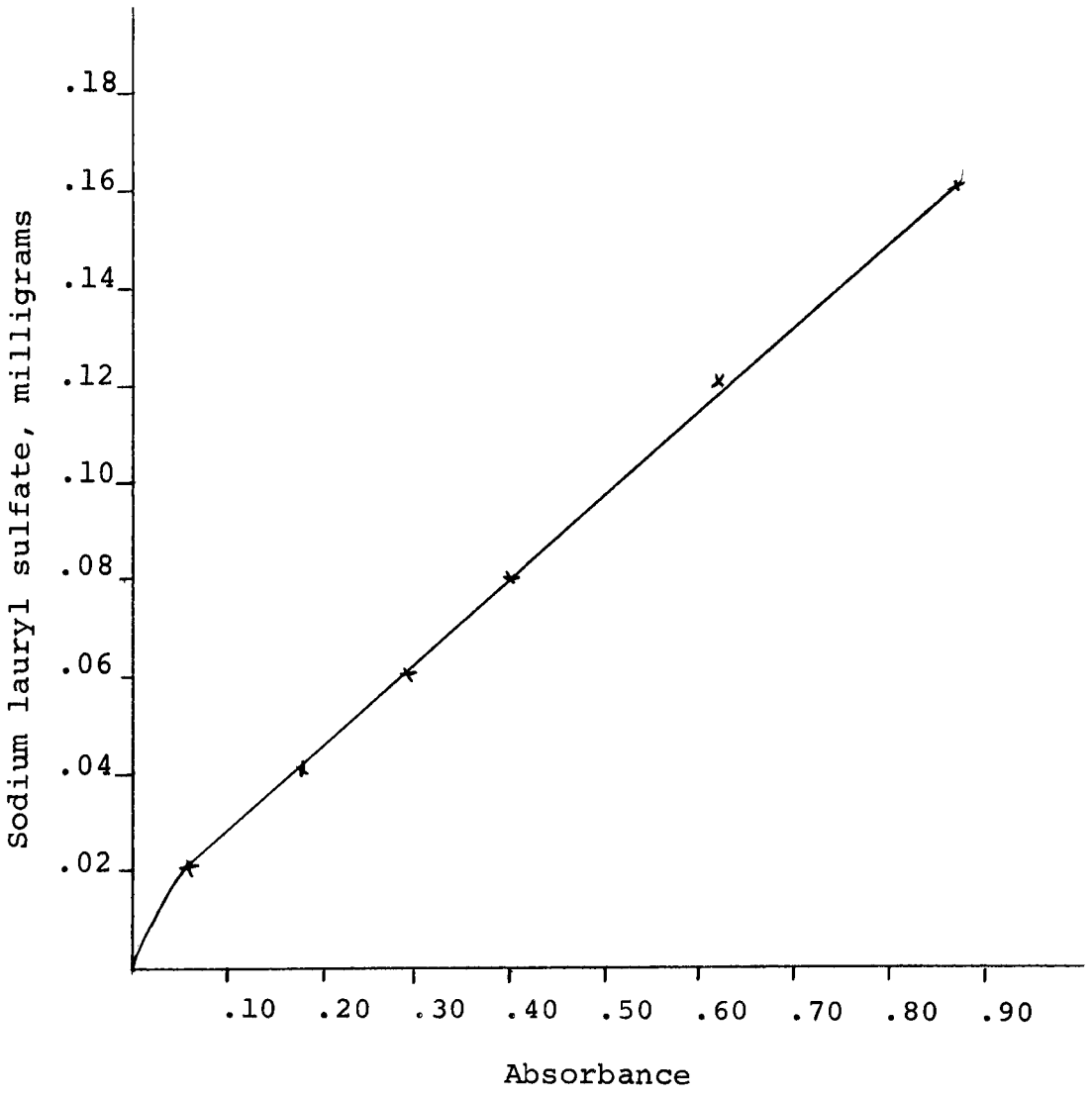


Figure 2. Sodium lauryl sulfate calibration curve.

the third rinse, one-half ounce of chlorine bleach was added to the water. The samples were rinsed in clean water then dried.

2. An aluminum six-quart kettle was preheated by allowing hot tap water to run into it for about two minutes. The kettle was emptied.

3. One gallon of hot tap water was placed in the kettle and 6 g of detergent were added.

4. The muslin samples were added and were agitated with a wooden spoon for ten minutes.

5. The samples were lifted from the kettle and squeezed gently by hand then hung on a rack to drip dry.

6. When dry, the samples were arranged randomly in groups of three.

7. These samples were placed on individual rungs of a rack in the oven.

8. The weighing bottles and covers were numbered, weighed on the analytical balance, and the weight recorded.

9. The uncovered bottles and covers were placed in the oven. The samples and the bottles were dried for two hours at 220°F.

10. The groups of samples were placed in their respectively numbered bottles. These uncovered bottles and their covers were placed in the desiccator and allowed to cool to room temperature.

11. The bottles, with covers replaced, were removed one at a time from the desiccator and weighed. The weight was recorded.

12. Steps 9 through 11 were repeated except the drying time was one hour. This procedure (Step 12) was repeated until constant weight within a precision of two parts per thousand was reached.

13. The samples were removed from the bottles and placed in correspondingly numbered Soxhlet extractor tubes. The samples were weighted down with a large Pyrex glass stopper.

14. The 250 ml flat bottom flask was filled one-half full of distilled water. The extractor tube and flask were placed in the Soxhlet extraction apparatus.

15. The Soxhlet heating unit was connected to the electrical outlet; the temperature was set at high.

16. The water cooling hoses were checked; the water was circulated continuously.

17. At four-hour intervals during the extraction period, the following procedure was carried out:

a. The flat bottom flasks of extract were removed and replaced with other flasks containing fresh distilled water.

b. The extract was poured into 2,000 ml volumetric flasks which were numbered the same as the Soxhlets; the extraction flasks were rinsed with small amounts of distilled water and this was poured into the volumetric flasks; the flasks were stoppered.

After twelve hours of extraction, the electrical unit of the extraction apparatus was disconnected and the cooling water was turned off. The following procedure was then performed.

1. The final extract was poured into the 2,000 ml volumetric flasks.

2. The extract was cooled to room temperature. Distilled water was added to the flasks to their capacity mark.

3. The extract in each flask was shaken gently but thoroughly so as not to produce suds.

4. Three 10 ml aliquots of extract from each of the three flasks were transferred into correspondingly numbered 30 ml beakers using a pipette.

5. A 10 ml aliquot of clean distilled water was transferred to a 30 ml beaker.

6. The extract samples and the distilled water were treated according to the procedure used in handling the samples prepared from purified SLS for the adjustment of the

pH (2, p. 20, 5.4.1.9) and the preparation of the blue chloroform solution samples (2, p. 20, 5.4.1.10). The blue chloroform solution prepared from the clean distilled water was used as the blank calibration standard in adjusting the spectrophotometer to read zero absorbance.

7. In addition to standardizing the spectrophotometer before any readings were taken, it was also standardized between each set of readings for samples prepared from a particular Soxhlet.

8. Two or three readings were made for each set of cuvettes and all readings were recorded.

9. The first set of readings was used in the preparation of data unless adjustments proved them to be inaccurate.

10. Using the measured absorbance values prepared from the purified SLS and plotted on the graph, the SLS content of each WCS Standard reading was determined and recorded.

Rinse Concentration Samples

Muslin samples which were removed from the washer loads were dried, extracted, and the extract treated in the same manner as the Standard of Wash Concentration samples with two exceptions:

1. As difficulty was encountered in adjusting the pH with a 0.1 N solution of HCL, a stronger solution of unknown normal was used to prevent the volume of the sample from becoming too large.

2. The extract from the Soxhlet was poured into a 1,000 ml volumetric flask.

The SLS content of each of the RCS readings was determined and recorded.

Detergent

The detergent selected was the leading high sudsing, heavy duty detergent on the market (17, p. 167). Its choice was based on its popularity. Sufficient quantity from one packing carton was purchased at the beginning of the experiment to control lot uniformity. Contents of the box were mixed well each time detergent was used (2, p. 20, 5.3.2). Detergent concentration for each machine was established according to AHAM specifications (2, p. 8, 1.6.3) with one exception: the amount of detergent used per gallon was always 6 g.

Conditioning of Machines, Loads, and Samples

Because the machines used during this experiment had previously been used, each was conditioned just prior to testing to remove any detergent buildup. This was done by operating the machine through a complete cycle at the normal setting using clean tap water to which one cup of the packaged softener was added during the wash-fill portion of the cycle. This was repeated twice more.

The load and the muslin samples were conditioned in the same way. This was done in the preconditioned machine. The purpose was to remove any filler or sizing present. During the wash portion of the third conditioning cycle, one-half ounce of chlorine bleach per gallon of wash water was added. As surfactant buildup was being measured, the fabrics were not reconditioned between cycles.

Water Hardness

Hardness of water was checked at a spigot near the test machine just prior to washing a load. Procedure followed was:

1. A 10 ml sample of cold water was taken from the spigot.
2. Three drops of Hack Chemical Company Solution 1 was added and the solution stirred to mix.
3. One Hack ManVer 11 Powder Pillow was added and the solution mixed thoroughly.
4. The sample was titrated with Hack TitraVer Solution until its color changed from pink to blue.
5. The grains per gallon of hardness were calculated as follows:

$$\frac{\text{ml of TitraVer used in titration} \times 100}{17.1}$$

One grain per gallon equals 17.1 parts per million.

Temperature

The temperature of the water was taken with a Fahrenheit mercury-in-glass thermometer inserted into the water in the tub to a depth of three inches at the point where the water entered the washer. This reading was taken just before the tub was completely filled with water during both the wash portion and the rinse portion of a cycle.

Energy Consumption

An electrical instrument panel containing a Variac, a voltmeter, and a watt-hour meter was used to control the voltage to the washer and to measure energy consumption. Voltage was maintained at the manufacturer's recommendation. Energy consumption readings were recorded at the:

1. beginning of each test cycle,
2. end of the wash portion of a cycle,
3. end of the rinse portion of a cycle, and
4. end of the spin dry periods.

Water Consumption

Commercial water meters were attached between the hot and cold faucets and the corresponding connections on the washers so that amounts of water used could be measured. At the beginning of each test wash cycle, the washer was pre-heated by filling it with hot water during the wash fill portion of the cycle then advancing the dial to the final spin

to empty. This was done to assure near constant machine temperature at the start of each test cycle. The meters were then set at whole numbers by allowing enough water to run into the washer to correct the reading then spinning the tub dry. It was felt that not enough water was allowed into the tub to affect the temperature of the tub. Water consumption was recorded at the:

1. beginning of a test cycle,
2. end of the wash portion fill,
3. end of the rinse portion fill,
4. end of any additions during the cycle, and
5. end of the cycle.

Laundry Cycle

The following procedure was followed for each cycle in the experiment:

1. The date and water hardness were recorded.
2. The washer was preheated; the water meters reset; the machine was emptied of all water by spinning.
3. The water meter and watt-hour meter reading were recorded.
4. The washer was loaded according to directions given in AHAM HLW-1 (2, p. 7); the detergent was added.
5. The washer controls were set; the washer turned on.

6. The temperature of the wash fill portion of the cycle was recorded.
7. The agitation time of the wash portion was controlled at ten minutes if the washer could be advanced easily to the next portion of the cycle, otherwise, the time was recorded.
8. The water and energy consumed during the wash agitation portion of the cycle were recorded.
9. The water and energy consumed during the first spin were recorded.
10. The temperature of the rinse fill was recorded.
11. The water and energy consumed during the rinse agitation portion were recorded.
12. The water and energy consumed during the final spin were recorded.
13. The load was placed in the dryer and dried automatically at the normal, heavy load cycle.

The following steps were carried out in handling the load and attached samples after the fifth, tenth, fifteenth, and twentieth laundry cycles:

1. The load was dried as above, removed from the dryer, fluffed, and redried as before.
2. The load was weighed and the weight recorded.
3. The load was dried for an additional ten minutes, then reweighed. This step was repeated until constant weight was obtained.

4. The samples designated for a particular load were removed (load 5, samples 1; load 10, samples 2; etc.).
5. The load and a number of stuffer samples were placed in the dryer for 10 minutes at the normal, heavy load setting. The load was weighed and enough stuffers added to the load to bring its weight to what it was before the test samples were removed.
6. The samples removed from the load were treated according to the procedure established for RCS.

IV. INSTRUMENTS AND EQUIPMENT USED IN THE STUDY

This section gives an explanation of the instruments and equipment used throughout the experiment.

Washers

The six washers used were labeled one through six for ease in tabulating data. They are listed below by the identifying number, name, model, and tub type.

1. Speed Queen, Model DA 9041, solid tub
2. Whirlpool, Model LVA 9920AE, perforated tub
3. Frigidaire, Model WIN, solid tub
4. Frigidaire, Model WCDN, solid tub
5. General Electric, Model WWA 8500N, perforated tub
6. Maytag, Model KA 806, perforated tub

Dryer

All loads were dried in a General Electric Clothes Dryer, Model DDE 7900N, using the Automatic Cycle, Heavy Load setting.

Oven

The muslin Samples used in the tests were dried to constant weight in the oven of a Frigidaire Custom Deluxe Range.

Electrical Instrument Panel

A small panel containing a Variac, a voltmeter, a wattmeter and a watt-hour meter was used with the washers. The Variac was used to maintain the voltage of the washers at the manufacturers' recommendations. The energy consumed was recorded from the watt-hour meter.

Water Meter

The hot and cold water used by the washers was measured with commercial water meters.

Thermometer

The temperature of the water in the washer tub was checked with a three-inch immersion, mercury-in-glass thermometer marked to read from 20° to 580° F and graduated in two-degree divisions.

Stop Watch

A stop watch was used to measure the time required for the wash portion of the laundry cycle.

Pound Scales

The load weights were determined with a set of Fairbanks-Morse Baby Scales graduated to .25 ounce.

Gram Balance

Ohaus Harvard Trip Scales were used in weighing the detergent for each laundry cycle. Two glass beakers of equal size were placed on the platforms and the scales balanced. The detergent was always weighed in the same beaker.

Analytical Balance

A William Ainsworth and Sons chainweight balance, Type BB, was used in weighing chemicals, weighing bottles, and muslin samples. Readings were taken in tenths of a milligram.

Soxhlet Extraction Apparatus

A Vari-Heat Soxhlet apparatus manufactured by Precision Scientific Company equipped with 24/40 - 250 ml Pyrex flat-bottom flasks and 45/50 cooling tubes was used to extract surfactant from the muslin samples.

pH Meter

A Beckman Zeromatic pH Meter was used in adjusting the pH of the extract samples to the desired level of hydrogen ion concentration.

Spectrophotometer

Absorbance of the chloroform extract prepared from the Soxhlet extract was determined with a Beckman Spectrophotometer, Model B.

Equipment Laboratory Items

A large slotted spoon was used to mix the detergent. A one-cup measure and measuring spoons of aluminum were used to fill the glass beaker with detergent. A glass measuring cup was used for the liquid bleach.

Chemistry Laboratory Items

The following items were used in connection with the handling of the samples for testing: weighing bottles, desiccator, beakers, separatory funnel, graduates, pipettes, volumetric flasks, and cuvettes designed for use with the spectrophotometer.

V. ANALYSES

Numerical data were analyzed statistically. The analysis of variance was used to find if there were significant differences at the .05 level between the two types of washers and among the washers within the types in the amount of surfactant removed by the method of rinse used. An analysis of covariance was used to determine if any significant differences, also at the .05 level, were indicated when the other variables,

temperature of the wash and the rinse water, total water and rinse water consumption, total energy and rinse energy consumption, and water hardness, were considered in interaction with the washers.

CHAPTER IV

RESULTS OF TESTS

Rinsing effectiveness of solid tub washers and of perforated tub washers was evaluated by measuring, with a spectrophotometer, the surfactant removed from the samples attached to the wash loads. The measurements were compared to surfactant removed from the saturated Standard. Temperature of the wash and rinse water, water and energy consumption, and the hardness of the water were recorded for each load. Raw data pertaining to these variables may be found in Tables V and VI of the Appendix.

I. FINDINGS ON AMOUNTS OF SODIUM LAURYL SULFATE (SLS) REMOVED

Analyzation of data pertaining to the amount of surfactant removed from Rinse Concentration Samples showed that the Grand Average of SLS removed was 54.77 percent with a Standard Deviation of 11.79 percent. Among the test loads for all washers in both types included in the experiment, the percent SLS removed ranged from a high of 79.23 percent to a low of 29.60 percent. This information is found in Table I which also provides data for the high and low percentages of SLS removed from test loads in each washer.

TABLE I

SODIUM LAURYL SULFATE REMOVED FROM SAMPLES IN TEST LOADS

Washer	Load Number	Percent SLS Removed	Percent Grand Total SLS Removed	Standard Deviation
1	5	71.87		
	10	46.70		
	15	66.07		
	20	66.38		
2	5	42.90		
	10	45.94		
	15	51.10		
	20	61.84		
			54.77	11.79
3	5	49.07		
	10	73.15		
	15	65.63		
	20	79.23		
4	5	46.68		
	10	46.43		
	15	53.56		
	20	29.60		
5	5	49.63		
	10	63.58		
	15	45.99		
	20	53.93		
6	5	57.87		
	10	47.70		
	15	41.19		
	20	58.55		

II. FINDINGS ON WASHER TYPES

The analysis of variance of the data pertaining to the washer types, washers among types, and loads in relation to the amount of SLS removed from the Rinse Concentration Samples showed no significant difference at the .05 level as shown in Table II. Accordingly, hypothesis one, that there is a significant difference in the amount of surfactant removed between types of washers, was rejected.

III. FINDINGS ON DIFFERENCES AMONG WASHERS WITHIN TYPES

The data in Table II further indicate that among the washers of both types included in the study, no significant differences in rinsing efficiency for removal of surfactant were found. Hypothesis two, there is a significant difference in the amount of surfactant removed in rinsing among washers within types, was rejected.

IV. FINDINGS IN REGARD TO THE EFFECTS OF WASH WATER AND RINSE WATER TEMPERATURES

Data in Table III show the mean wash water temperature for all test loads in all washers was 141°F. Wash water temperatures ranged from a high of 154°F to a low of 132°F. Rinse water temperature varied from 108°F to 86°F. These

TABLE II

ANALYSIS OF VARIANCE FOR DIFFERENCES BETWEEN TYPES OF WASHERS, WASHERS WITHIN TYPES, AND LOAD NUMBER IN RELATION TO PERCENT SLS REMOVED

Source	d.f.	m.s.	F value[a]
Total	23	-	-
Type	1	229.00	1.86
Washer/type[b]	4	297.81	2.42
Load	3	33.41	0.27
(Type x load)	3	67.34	0.55
Residual	12	123.05	-

[a]Not significant at .05 level.

[b]The proper error term for testing type was deemed to be washer/type.

TABLE III

SIMPLE STATISTICS OF VARIABLES INVOLVED IN ANALYSIS OF COVARIANCE

Variable	Sum	Mean	Corrected Sum of Squares	Standard Deviation
Wash Temperature in °F	3395	141	573	5
Rinse Temperature in °F	2306	96	1206	7
Total Water in Gallons	802.54	33.44	321.77	3.74
Rinse Water in Gallons	474.64	19.78	72.85	1.78
Total Energy in Watt-hours	5083.20	211.80	25252.82	33.14
Rinse Energy in Watt-hours	2902.70	120.95	9292.14	20.10
Hardness in gpg	126.50	5.27	63.30	.52

variations are reported in Table V of the Appendix. Table III shows the mean for rinse water temperature as 96°F. In the analysis of covariance, neither the temperature of the wash water nor the temperature of the rinse water was found to make a significant difference in the rinsing efficiency of any of the washers in either type in removing surfactant, and hypothesis three was rejected.

V. FINDINGS ON WATER CONSUMPTION

Continuing with an analysis of covariance, the total amount of water used in a complete laundry cycle and in the rinse portion of the cycle only were considered. Table III shows a mean of 33.44 gallons for total water used. This figure considered all test loads in all washers. Table V shows a high of 40.40 gallons and a low of 27.58 gallons being used.

For rinse water only, Table III discloses a mean of 19.78 gallons. Table V shows that as much as 23.30 gallons and as little as 17.41 gallons of water were used in rinsing.

Hypothesis four, there are significant differences in the rinsing efficiency between types of washers in removing surfactant in relation to the amounts of water consumed, was rejected.

VI. FINDINGS ON ENERGY CONSUMPTION

The mean amount of energy used by all washers in a total laundry cycle was shown to be 211.80 watt-hours. The mean for energy consumed during the rinse portion of the cycle was 120.95 watt-hours. These data may be found in Table III, page 39. Although the raw data in Table VI, Appendix, show a spread from 266.60 watt-hours to 162.70 watt-hours for total energy used and a high of 157.80 watt-hours and a low of 89.00 watt-hours used in rinsing only, the analysis of covariance for the inclusion of these variables revealed no significant difference in rinsing efficiency in removing surfactant in any of the washers. Hypothesis five was rejected.

VII. FINDINGS ON HARDNESS OF WATER

The hardness of the water during the testing period ranged from 4.4 grains per gallon (gpg) to 6.0 gpg. Average hardness figures for all test loads are shown in Table VI. The mean for water hardness was calculated at 5.27 and is shown in Table III. The addition of this variable to the analysis of covariance produced no significant difference in the amount of surfactant removed by washers with solid tubs in comparison to washers with perforated tubs. Hypothesis six was rejected.

Data showing the mean square and "F" values of the washers when all the variables were considered in the analysis of covariance are provided in Table IV.

TABLE IV

ANALYSIS OF COVARIANCE FOR ALL WASHERS WITHIN TYPES IN RELATION TO PERCENT SLS REMOVED

Source	d.f.	m.s.	F value[a]
Total	23	-	-
Type	1	101.70	0.41
Washer/type[b]	4	89.72	0.36
Load	3	10.01	0.04
(Type x load)	3	96.00	0.38
Wash Temperature	1	47.84	0.19
Rinse Temperature	1	93.25	0.37
Total Water	1	111.18	0.44
Rinse Water	1	156.04	0.62
Total Energy	1	2.20	0.01
Rinse Energy	1	29.95	0.12
Hardness	1	37.63	0.15
Residual	5	250.73	-

[a]Not significant at the .05 level.

[b]The proper error term for testing type was deemed to be washer/type.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was designed to evaluate the rinsing efficiency of solid tub and perforated tub clothes washers and the method of rinsing each utilized to determine if one were more effective than the other in removing surfactant from a laundry load. The study included six washers, three of each type.

Identical six-pound loads of new, unsoiled, cotton linens were laundered twenty times in each of the washers. Muslin samples attached to the load were removed every fifth load, the surfactant extracted from them, and this extract examined with a spectrophotometer to determine surfactant content. This information was compared with data collected from a set of saturated samples designated as a Standard. Other data collected were the temperature of the water, water and energy consumption, and hardness of the water.

Factors which were controlled were the type and amount of detergent used, the voltage of the circuit, and the wash agitation time.

It was hypothesized that on the hot wash, warm rinse setting, automatic washers with solid tubs differ significantly from those with perforated tubs in the amount of

surfactant removed by the method of rinsing utilized and that this difference is influenced by the temperature of the water, the amount of water and energy used, and the hardness of the water. It was also hypothesized that there was a significant difference in the rinsing efficiency among the washers in the two types. All six hypotheses were rejected after data were analyzed by analysis of variance or analysis of covariance.

The results of the study indicate that as the washers are presently designed, one was as effective as another in the removal of surfactant. That all the washers did less than a satisfactory job is indicated by the fact that on the average only about 54 percent of the surfactant was removed. The use of less surfactant might be a possible solution; however, when the amount of detergent used as weighed in grams was converted to measurement in cups, these amounts fell within the detergent manufacturer's recommendation.

There is need for further study. Although a load of six pounds had been recommended by several studies cited in the literature reviewed, a smaller load composed of the same types of items used in this study could be substituted. Another possibility would be a study using the manufacturer's advertised capacity of the washer. A low sudsing detergent could be substituted. The need for an additional rinse, deep or flush depending on tub type, may be indicated. One washer used in the study provided for this within the cycle.

Until the problem can be solved, the consumer of a particular washer will have to be her own experimenter, testing load content and size, types of detergents, number of rinses, and temperature and hardness of the water to determine what combination will provide her with the most surfactant-free laundry.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. AHAM Specification Book 1972 - Home Laundry Appliances, Chicago, Illinois: Association of Home Appliance Manufacturers, 1972.

2. An American National Standard Performance Evaluation Procedure For Household Washers, Chicago, Illinois: Association of Home Appliance Manufacturers, 1970.

3. "Automatic Washing Machines." Consumer Bulletin, Vol. 54 (April, 1971), pp. 7-12.

4. Beale, Margaret. "Removal of Soil From Fabric Laundered in Home Washers II. Soft and Hard Water; Amount of Soap; Number of Rinses." Unpublished Master's thesis, Iowa State University, Ames, Iowa, 1952.

5. Craft, Naomi. "Lighten Your Laundry Load," Bulletin No. HE-64. Ames, Iowa: Iowa State University Cooperative Extension Service, 1965.

6. Donovan, Alicia. "1972 Statistical and Marketing Report." Merchandise Week, Vol. 104 (February 28, 1972), pp. 61-70.

7. Ehrenkranz, Florence. "Effects of Different Detergents on Appearance of Home Laundry Washed in Different Appliances." Soap and Chemical Specialities, Vol. 36 (May, 1960), pp. 47-50.

8. Faragher, W. F. "An Investigation into the Chemistry of Laundering." Industrial Engineering Chemistry, Vol. 6 (1914), pp. 640-649.

9. Goodhue, Irene. "Automatic Washers." Newton, Iowa: Maytag Company. Paper delivered at the Sixth National Laundry Conference, New York, New York, October 30, 1952.

10. Home Laundering Terms, Chicago, Illinois: Association of Home Appliance Manufacturers, n.d.

11. Loeb, Leo. "Effective Laundry Aids, Techniques." Louisville, Kentucky: General Electric Company. Paper delivered at the Seventeenth National Laundry Conference, Boston, Massachusetts, November 21, 1963.

12. "Methods and Equipment for Home Laundering," United States Department of Agriculture Farmers' Bulletin No. 1497. Washington, D. C.: Government Printing Office, 1940.

13. "Performance Test Methods for Home Laundry Detergents." Material Research and Standards, Vol. 10 (August, 1970), pp. 25-28, 42-43.

14. Potter, P. B. "Home Laundry Investigations," Research Bulletin 361. Blacksburg, Virginia: Virginia Agricultural Experiment Station, 1944.

15. Roberts, Evelyn H. "The Efficiency of the Home Laundry Plant," Bulletin No. 248. Pullman, Washington: State College of Washington Agricultural Experiment Station, 1931.

16. Ross, Enid Sater, Katherine Taube, and Dorothy S. Greene. "Home Washing Machines - Operating Characteristics and Factors Affecting Performance," United States Department of Agriculture Technical Bulletin No. 1088. Washington, D. C.: Government Printing Office, 1954.

17. Rukyser, William Simon. "Facts and Foam in Row Over Phosphates." Fortune, Vol. LXXXV (January, 1972), pp. 71-73, 166-170.

18. Smith, Allen W. "Soaps--Syndets." Midland, Michigan: Dow Chemical Company. Paper Delivered at the Seventh National Home Laundry Conference, New York, New York, November 5, 1953.

19. Snell, Cornelia T. "Methods of Evaluating Detergents." American Dyestuff Reporter, Vol. 39 (July 24, 1950), pp. 485-487.

20. Synder, Edna B., and Morton P. Brunig. "A Study of ff Washing Machines," Bulletin No. 56. Lincoln, Nebraska: University of Nebraska Agricultural Experiment Station, 1931.

21. Tide Washday Notes #32, Cincinnati, Ohio: Procter and Gamble, n.d.

22. Weaver, Elaine K. "A Study of the Use of Three Types of Automatic Washers," Bulletin No. 715. Wooster, Ohio: Ohio State University Agricultural Experiment Station, 1954.

23. Williams, Velma Lorraine. "Removal of Soil from Fabric Laundered in Home Washers I. Soft and Hard Water; Number of Rinses and Temperature of Rinse Water." Unpublished Master's thesis, Iowa State University, Ames, Iowa, 1951.

APPENDIX

TABLE V

RAW DATA COLLECTED REGARDING THE VARIABLES OF WATER TEMPERATURE AND AMOUNT OF WATER CONSUMED FOR EACH EXPERIMENTAL WASHER

Washer	Average of Loads	Temperature Wash Water °F	Temperature Rinse Water °F	Total Water in Gallons	Rinse Water in Gallons
1	1-5	138	93	36.28	23.30
	6-10	132	93	35.95	20.48
	11-15	140	95	34.48	20.50
	16-20	136	92	32.95	21.10
2	1-5	136	108	34.08	18.42
	6-10	137	108	33.35	18.00
	11-15	138	106	34.08	18.60
	16-20	139	108	33.05	17.68
3	1-5	141	103	31.42	19.80
	6-10	139	103	31.25	19.45
	11-15	144	104	30.78	19.40
	16-20	140	104	29.15	17.41
4	1-5	138	98	29.90	18.55
	6-10	140	92	28.00	17.92
	11-15	138	91	29.52	19.58
	16-20	140	92	27.58	18.50
5	1-5	146	89	40.40	22.65
	6-10	147	90	40.40	22.85
	11-15	146	88	39.52	22.25
	16-20	145	88	39.92	22.52
6	1-5	147	92	32.58	19.02
	6-10	146	90	33.09	19.06
	11-15	154	94	32.40	18.62
	16-20	148	86	32.42	18.98

TABLE VI

RAW DATA COLLECTED REGARDING THE VARIABLES OF ENERGY CONSUMPTION AND HARDNESS OF THE WATER FOR EACH EXPERIMENTAL WASHER

Washer	Average of Loads	Total Energy	Rinse Energy	Water Hardness
1	1-5	260.20	153.20	4.8
	6-10	266.60	157.80	4.6
	11-15	262.00	152.00	4.8
	16-20	253.20	143.60	4.4
2	1-5	230.60	121.80	6.0
	6-10	226.80	127.00	4.6
	11-15	234.50	128.70	5.2
	16-20	228.20	124.20	5.8
3	1-5	200.00	116.20	5.0
	6-10	206.00	124.60	5.0
	11-15	190.80	111.60	5.0
	16-20	205.20	124.40	5.0
4	1-5	175.40	100.00	5.0
	6-10	178.80	104.40	6.0
	11-15	179.20	102.00	5.6
	16-20	187.60	110.20	6.0
5	1-5	234.60	135.60	4.8
	6-10	232.00	133.00	5.0
	11-15	231.80	132.60	6.0
	16-20	230.00	131.80	5.6
6	1-5	173.00	95.40	5.8
	6-10	167.80	92.00	6.0
	11-15	166.20	91.60	5.5
	16-20	162.70	89.00	5.0

VITA

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