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HOME WASHING MACHINES OPERATING CHARACTERISTICS AND FACTORS AFFECTING
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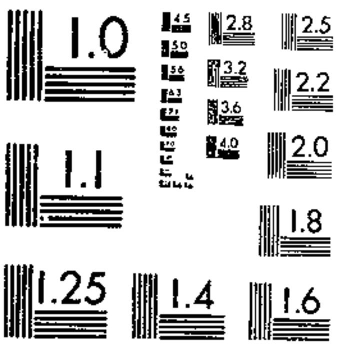

MICROCOPY RESOLUTION TEST CHART
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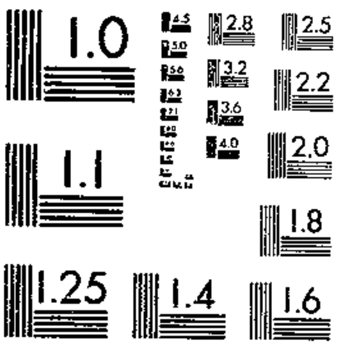

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Home Washing Machines—Operating Characteristics and Factors Affecting Performance[1]

BY ENID SATER ROSS and KATHERINE TAUBE, *household equipment specialists*, and DOROTHY SKINNER GREENE, formerly *household equipment specialist*, *Home Economics Research Branch, Agricultural Research Service*[2]

CONTENTS

PURPOSE AND SCOPE OF STUDY

Since World War II, many new models and designs of home washers have become available; some, particularly among the automatics, are radically different from those of prewar years. Prospective buyers are interested in the comparative performance of automatic and nonautomatic washers, in the amount of water needed by automatics, and in the effect on fabrics of the various types of washing mechanisms. Those who have already bought machines are seeking information on how to use them to obtain the most satisfactory washing results.

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[1] Submitted for publication December 1953.

[2] Acknowledgment is made to Paul G. Homeyer, Iowa State College Statistical Laboratory, for assistance in the statistical work, and to the following for contributions in various phases of the investigations: Marilyn Girton Fisher, Homoselle Jarvis, Nada Poole, Isabelle Marron Shirley, and Mabel Sterling.

To obtain technical information as a basis for the preparation of buying guides and directions for efficient use and care of washing machines, a study was made of the operating characteristics and of some factors affecting the performance of automatic, nonautomatic, and semiautomatic machines typical of the designs on the market in the late 1940's. The study included the following:

1. Comparison of the soil-removing ability of the different kinds of washers—automatic, nonautomatic, and semiautomatic—and of the different types of washing mechanisms—agitator, modified agitator, agitating basket, and cylinder.
2. Determination of the effect of certain factors in the washing process, such as weight of load, soaking, temperature of wash water, amount of detergent, washing time, method of water extraction, and temperature of rinse water, on soil removing ability of washers.
3. Effect of different types of washing mechanisms and water extractors on breaking and bursting strengths and dimensional changes of some selected fabrics commonly believed to be adversely affected by mechanical action.

REVIEW OF LITERATURE

A review of the literature on home laundering equipment and procedures for its use revealed lack of agreement in recommendations and omission of supporting data. This pointed up the need for more research using standardized testing methods and techniques.

Snyder and Brunig in 1931 (*21*) [3] reported that gyrator [4] machines caused the least wear on fabrics studied, and dolly machines the most. They found that soiled samples washed in gyrator machines reached maximum brightness in a shorter time than in other types (cylinder, vacuum, and dolly). They also reported better soil removal with water of medium temperature (about 125° F.) than with higher or lower temperatures, and observed that the optimum load for each machine, below or above which poorer washing results, was not always the load recommended by the manufacturer.

Roberts (*20*) studied the efficiency of the home laundry, giving special attention to temperature and methods of washing.

Peet and Johnson (*16*) investigated cleaning action of washers in relation to design of tub and agitator, using artificially soiled cotton sheeting as a test material and measuring soil removal by light reflectance as determined by a reflectometer. Their study indicated a need for manufacturers to correlate the size and shape of tub with the speed and angle of oscillation of the agitator.

Potter (*19*) compared the washing ability of different types of washing mechanisms and investigated several factors affecting the washing process. He reported the underwater gyrator machine first in washing ability in a group including also vacuum-cup and cylinder types, recommended 150° F. water for washing, stated that it is possible to wash clothes too long, and cautioned against overloading the machines.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 38.
[4] Gyrator mechanisms are now called agitators.

WASHERS STUDIED

The 19 washers selected for the study here reported were representative of the different types on the market at the time the study was started—automatic, semiautomatic, and nonautomatic—and of the different kinds of washing mechanisms—agitator, modified agitator, agitating basket, and cylinder.

Certain design and operating characteristics of the washers used are summarized in table 1.

The manufacturers' ratings for size of load for the washers, with one exception, varied from 8 to 10 pounds of dry clothes. One washer was rated at 18 pounds.

Water capacity of the tubs as measured in the laboratory ranged from 6.5 to 20.5 gallons. The amount of hot water per load required by an automatic washer depends on the water capacity of its tub, temperature of the water supplied, and temperature of the rinse water used. The rinse cycle of most of the washers studied used water of approximately 100° F. Some used cold water, as shown in table 1. With water from heaters set at 150° to 160° F., the quantity of hot water used by the 11 automatic washers studied ranged from 13 to 39 gallons per cycle.

According to manufacturers' specifications, activations per minute for the washing mechanism of the machines studied ranged from 44 to 300, and spinner water extractors ranged in speed from 272 to 1,130 revolutions per minute.

Laboratory tests to measure the effectiveness of the machines in removing water from clothes showed that the water left in the clothes after water extraction increased their weight by an average of 93 percent for wringer machines and 83 percent for spinners. The range for all machines was from 46 to 134 percent.

EXPERIMENTAL PROCEDURES [5]

Preparing Artificially Soiled Fabrics

Though no two workers have reported identical procedures for testing domestic washers, most workers have used artificially soiled cloth rather than naturally soiled clothes for measuring the effectiveness of the machines in removing soil. Naturally soiled clothes vary from week to week among families and individuals, making it impossible to control the nature, degree, and age of the soil deposit for scientific testing.

In this study the fabric used for soiling was a bleached cotton sheeting 45 inches wide, 105 yarns to the inch in warp and 91 in filling, weighing 3.9 ounces per square yard—the type of fabric previously used for soiling in a study of detergents by Furry and associates (*7*). The fabric cut into strips 204×12 inches was degreased and desized by an adaptation of the method outlined in A. S. T. M. D629-46T (*1*).

[5] More detailed description of techniques of experimentation in mimeographed form are available to research workers on request.

TABLE 1.—*Design specifications and performance characteristics of 19 washers*

Type of washer and mechanism [1]	Tub diameter	Agitator		Motor			Load (manufacturer's rating)	Tub capacity
		Diameter	Fins	Manufacturer's rating		Washing with a 6-pound load		
	In.	*In.*	*No.*	*H. p.*	*Amp.*	*Amp.*	*Lb.*	*Gal.*
Automatic:								
A Agitator	19¾	11 1/16	3	------	9.8	7.5	8	14.0
B Agitator	18½	11¼	3	¼	6.0	7.2	9	13.5
C Agitator	21½	13 1/16	4	------	5.5	5.9	8	15.0
D Agitator	21	11 15/16	3	⅓	7.0	6.2	[illegible]	16.0
E Agitator	21¼	11¼	3	⅓	12.0	7.5	9	19.0
F Agitator	21⅜	11 15/16	3	------	------	6.2	9	17.0
G Modified agitator	19 13/16	------	------	⅓	8.0	7.3	8	11.0
H Agitating basket	23	------	------	⅓	7.0	5.2	8	7.0
I Cylinder	25⅜	------	------	⅓	------	5.5	9 to 18	[2] 9.0
J Cylinder	19⅜	------	------	¼	6.0	6.2	9	6.5
K Cylinder	18¾	------	------	¼	7.0	------	10	10.0
Semiautomatic:								
L Agitator	19 5/16	15	6	¼	------	------	8	11.0
Nonautomatic:								
M Agitator	22	11½	3	¼	5.2	5.7	8	20.0
N Agitator	22⅜	13 13/16	3	¼	4.8	4.8	8	19.5
O Agitator	22¼	11 7/16	3	------	4.8	4.3	8	16.5
P Agitator	21 9/16	13	3	------	4.8	4.5	8	16.0
Q Agitator	22	9¼	3	------	4.3	------	8	16.0
R Agitator	21¾	11 15/16	4	⅓	3.6	5.3	8	15.0
S Agitator	23	11 15/16	3	------	6.0	4.9	9	20.5

See footnotes at end of table.

TABLE 1.—*Design specifications and performance characteristics of 19 washers*—Continued

Type of washer and mechanism [1]	Water for cycle		Cycle [2]	Activations or revolutions per minute		Moisture content of clothes after extraction
	Hot	Cold		Wash	Spin	
	Gal.	*Gal.*		*No.*	*No.*	*Pct. of dry weight*
Automatic:						
A Agitator	14	31	Wash, warm spray, cold spray, cold overflow rinse.	65	650	85
B Agitator	30	17	Wash, overflow rinse; fixed cycle after wash.	70	550	86
C Agitator	28	17	Wash, 2 deep rinses	58	...	122
D Agitator	20	15	Wash, 4 sprays, 1 deep rinse, 2 sprays.	68	500	82
E Agitator	39	21	Prewash, wash, 1 deep rinse	70	1,100	46
F Agitator	24	12	Wash, 4 sprays, 1 deep rinse, 2 sprays.	72		83
G Modified agitator	21	12	Wash, 2 deep rinses	300	1,130	54
H Agitating basket	13	13	Wash, 2 deep rinses		550	75
I Cylinder	[3] 17	[3] 16	Prewash, wash, 2 deep rinses	56	272	134
J Cylinder	18	13	Prewash, wash, spray, 2 deep rinses.	59	333	106
K Cylinder	18	12	Wash, 2 deep rinses; fixed cycle	51	375	99
Semiautomatic:						
L Agitator	21	9	As selected by operator; manufacturer recommends 10-minute agitated rinse followed by 4-minute overflow rinse.	52	600	75
Nonautomatic:						
M Agitator				64		84
N Agitator				58		100
O Agitator				64		94
P Agitator				44		101
Q Agitator				58		64
R Agitator				62		101
S Agitator				54		101

[1] All automatic washers have spinners for water extraction except C, which has a collapsible tub; the semiautomatic has a spinner; all nonautomatics have wringers except Q, which has a spinner. All washers have top openings except I and J, which have front openings.

[2] Unless otherwise indicated the cycle may be adjusted for length of wash period and parts of cycle may be repeated or omitted as desired. The kinds of rinses are defined as follows: Spray rinse, rinsing in spray of water while clothes are in a slow spinning action; deep rinse, in a tub of water; overflow rinse, in water that is continuously changing. All rinses are warm unless otherwise stated.

[3] Filled on medium setting.

The soiling solution was a mixture of 6 grams tallow, 20 grams mineral oil, 8 grams colloidal graphite in oil, and 4 liters of carbon tetrachloride, applied at room temperature with the soiling machine described by Furry (*7*). The ends of each strip were sewed together to form a continuous piece. By a system of moving rollers this was passed through the soiling solution 11 consecutive times to obtain the desired degree of soil.

After air drying, the soiled strips were cut into 4- by 4-inch samples. They were stored in a household refrigerator at approximately 38° F. and used within 2 weeks.

Determining Light Reflectance of Samples

Changes in light reflectance of fabrics brought about by washing is used in most reported research as the measure of soil removal. Hill (*9*), Morgan (*14*), Peet and Johnson (*16*), Potter (*19*), and Mack (*12*) used light reflectance to measure soil on samples before and after washing.

In this study, the difference in the light reflectance of the unwashed soiled sample and that of the washed sample was used as a measure of soil removed. A reflectometer was used for measuring light reflectance (fig. 1).[6]

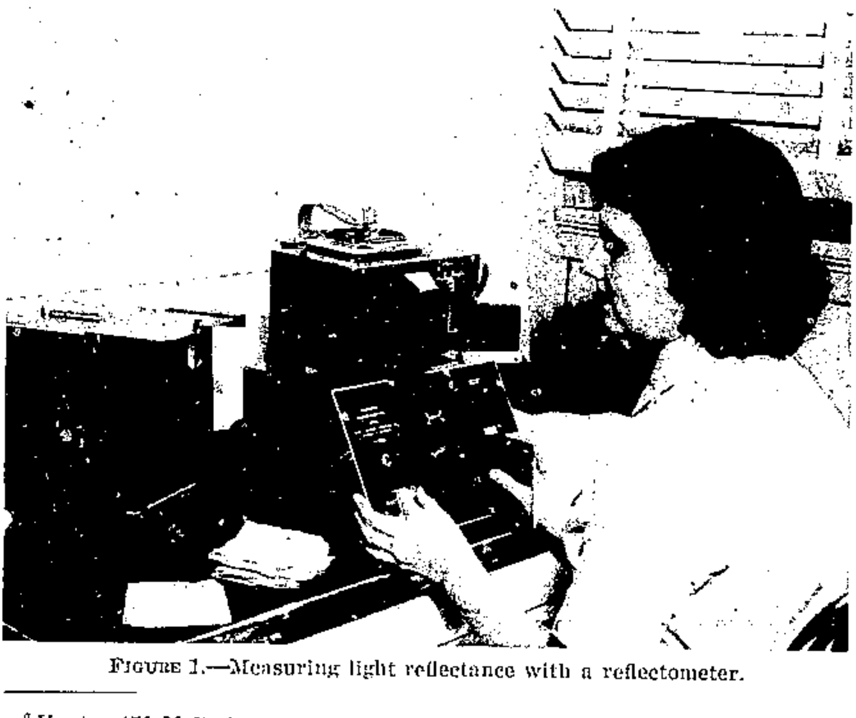

Figure 1.—Measuring light reflectance with a reflectometer.

[6] Hunter 45° 0° Reflectometer with standard porcelain-enameled plates reflecting calibrated percentages of incident light: White 78.8 percent (for white samples); light gray 40.3 percent (for washed soiled samples); dark gray 9.45 percent (for unwashed soiled samples).

The average of two readings of the same location on a sample was used as the reflectance value of a sample. The dark underfacing of the spring cover over the aperture of the reflectometer was used as the backing for both the soiled and washed samples. To obtain sets of soiled samples with identical reflectance values from set to set, the code numbers of the samples were first arranged according to reflectance values as in table 2, which gives the array of 150 samples from one strip. From such a table the numbers were grouped in sets of 10 to be washed together, each set made up of samples with corresponding values.

After washing, whatever the method, samples were thoroughly dried at room temperature and stored in a covered container until read. Exactly the same area of the sample was read after washing as before.

TABLE 2.—*Samples from one soiled strip, arrayed according to reflectance values*

Reflectance values												
11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1	12.2	12.3	12.4
46	----	19	2	8	7	5	1	9	106	6	12	3
		40	4	16	10	11	18	39	126	112		
		47	13	17	35	15	33	42		132		
		59	14	21	52	24	36	64		135		
		61	20	22	57	27	37	81				
		148	23	28	60	32	86	95				
			25	29	65	34	89	100				
			26	30	71	38	90	102				
			43	31	77	53	94	107				
			44	41	88	54	99	108				
			45	48	91	63	117	111				
			51	49	92	69	125	114				
			55	50	98	70	133	121				
			56	66	104	72	136	122				
			58	67	109	74	139	123				
			62	68	110	75	144	127				
			82	73	124	76	147	129				
			83	78	128	79	150	138				
			103	84	131	80		141				
			119	116	143	85						
			140			87						
			145			93						
			146			96						
						97						
						101						
						105						
						113						
						115						
						118						
						120						
						130						
						134						
						137						
						142						
						149						

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Measuring Soil-Removing Ability of Washers

The ability of washers to remove artificial soil from fabric is expressed as the ratio of the change in light reflectance of samples washed in one load in the washer under study to the change in light reflectance of a like set of samples washed in one load in the Comparator, a washer developed by the American Home Laundry Manufacturers Association[7] to be used as a standard for comparing performance of household washers (fig. 2).

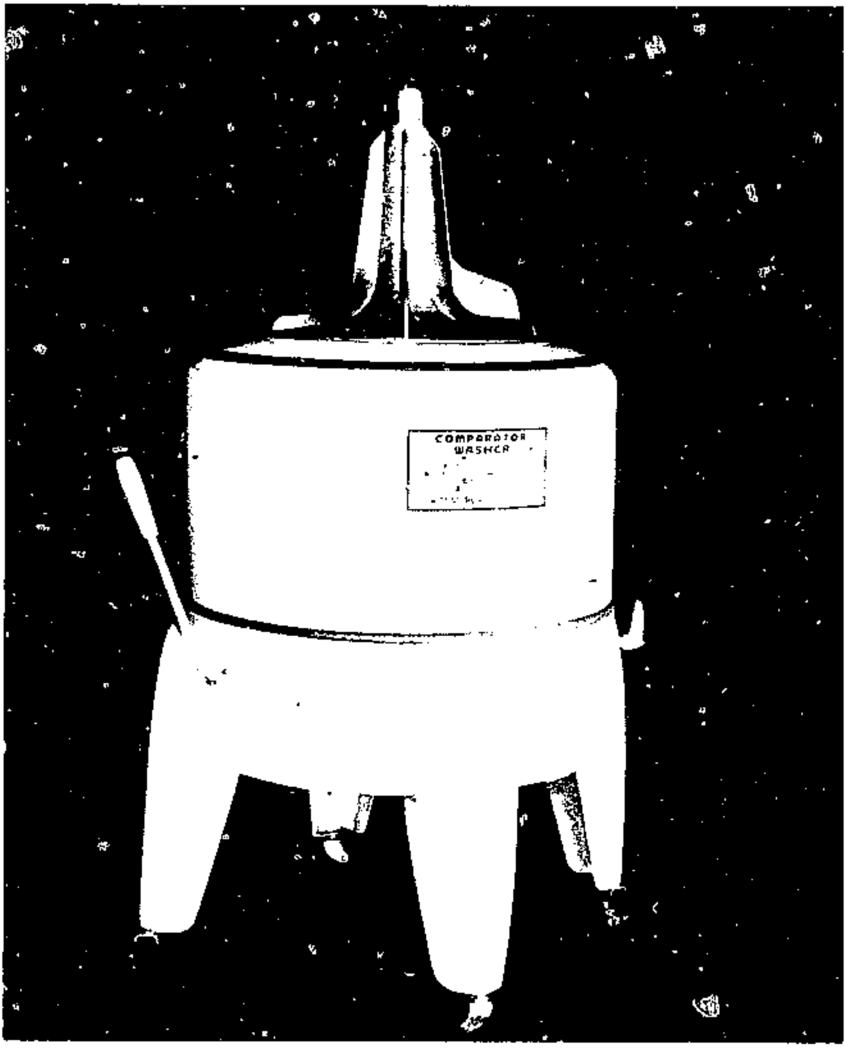

Figure 2.—Comparator washer.

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[7] 20 North Wacker Drive, Chicago 6, Illinois.

Expressed as a formula:

$$\text{Soil-removal index} = \frac{\text{Sum of light reflectances of samples washed by the machine under study minus the sum of light reflectances of the same samples before washing}}{\text{Sum of light reflectances of samples washed by the Comparator minus the sum of the light reflectances of the same samples before washing}} \times 100$$

As used in this report the soil-removal index of a washer expresses the number of artificial soil units that washer removed compared with 100 units removed by the Comparator washer, as evaluated for each load. The indexes were averaged for final values reported. In experiments in which results from different washers are compared, the conditions for washing in the Comparator remained constant, while the conditions in the other washers varied according to the particular object of the investigation. Therefore, the soil-removal index for a given washer may vary, depending upon the conditions of use.

Washing Procedures

With Comparator Washer.—At least one load was washed in the Comparator washer each day of experimentation. The soiled samples in the load were the same in number, from the same strip, and had the same reflectance values as those washed in the machines under study. The individual soiled samples, 4 by 4 inches square, were pinned at their 4 corners over a hemmed opening in the center of a muslin square. With two exceptions, which are explained as experiments are discussed, the washing procedure in the Comparator was always the same. The tub was filled with 15 gallons of 140° F. water and 30 grams of nonprecipitating water softener were mixed with the water. Three pounds of clean muslin squares with the pinned-on soiled samples were added and agitated for 10 minutes. The squares were removed without water extraction, and the samples were unpinned and spread on a glass surface to dry.

With Washers Under Study.—In experiments designed to study the effect on soil removal of weight of load, method of water extraction, and length of wash period, washings were done without detergents. Detergents were used in experiments to determine the effect of different temperatures of water in washing and of various methods of soaking and rinsing, as well as of different concentrations of detergent. With the exceptions noted in certain experiments, a load of 6 pounds was used.

In washing without detergent, washers were filled with water at 140° F. (±1°) in the amount required for a full washing load. Two grams of nonprecipitating water softener per gallon of water were added and dissolved by agitation. The load, consisting of clean cotton squares with soiled samples attached, was put in and agitation begun. After 10 minutes, the washer was stopped and the cotton squares taken out without water extraction. The samples were removed and spread on glass to dry.

For experiments in which detergents were used, the loads usually were made up of naturally soiled materials in addition to the artificially soiled samples. The washing procedure was the same as that described above, except that detergent instead of softener was added to the water and thoroughly dissolved by agitation before the clothes were placed in the machine.[5]

In wringer machines, the clothes were put through the wringer, returned to the tub which had been emptied and refilled with 100° F. water, agitated for 3 minutes, and wrung again. The clothes were then given a second rinse like the first. In nonautomatic and semiautomatic spinner machines the procedure was the same except that a 2-minute spin replaced the wringing after the wash and first rinse; a 5-minute spin was used after the second rinse. Automatic machines were allowed to complete their regular cycle after the 10-minute washing period. The washed, rinsed, and extracted samples were removed from the pieces to which they had been pinned and placed flat on a glass surface to dry at room temperature.

EFFECT OF CERTAIN FACTORS ON WASHER PERFORMANCE

In the study of washer performance, the effects of the following design factors and methods of procedure on the machines' ability to remove soil were investigated: Kind of washer (automatic, semiautomatic, nonautomatic), type of washing mechanism (cylinder, agitator), tub capacity, weight of load, soaking of clothes, temperature of water used for washing, concentration of detergent, method of water extraction, length of wash period, and temperature of rinse water. Not all washers were used in all experiments.

Type of Washer, Washing Mechanism, and Tub Capacity

Judged by performance with 6-pound loads washed without detergent according to the procedure described on page 9 no one kind of washer or type of washing action was consistently better in soil-removing ability than the others, as table 3 shows. Of the 19 washers studied, the 4 having the highest soil-removal indexes were automatic. Indexes for the others were intermingled in no particular order. The most effective washer and the 4 least effective were of the agitator type. The 3 cylinder machines were among the top 7 in ranking. The soil-removal indexes for automatics ranged from 76 to 115; those for the nonautomatics ranged from 64 to 88.

Statistical analysis of the data from the agitator-type washers showed highly significant differences among some but not among all washers. The data were arranged in numerical progression and a test was made between each pair of adjacent figures and then between those having greater differences to determine where the significant differences occurred. In this way it was possible to separate the data into groups significantly different from other groups, but within which

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[5] In washer G a special container was provided for the detergent; clothes were put into clear water and a few seconds after the washer action started, the detergent was dissolved in the water.

TABLE 3.—*Washers by type ranked in descending order according to soil-removal index with a 6-pound load*

Type of washer and mechanism	Soil-removal index [1]	Tub capacity
Automatic:		*Gallons*
A Agitator	114. 8	14. 0
I Cylinder	102. 7	9. 0
B Agitator	100. 8	13. 5
C Agitator	97. 3	15. 0
J Cylinder	90. 3	6. 5
K Cylinder	88. 3	10. 0
H Agitating basket	86. 1	7. 0
D Agitator	85. 6	16. 0
E Agitator	83. 9	19. 0
G Modified agitator	78. 6	11. 0
F Agitator	75. 9	17. 0
Semiautomatic:		
L Agitator	95. 8	11. 0
Nonautomatic:		
M Agitator	87. 9	20. 0
N Agitator	86. 0	19. 5
O Agitator	83. 2	16. 5
P Agitator	78. 9	16. 0
Q Agitator	73. 5	16. 0
R Agitator	66. 7	15. 0
S Agitator	64. 1	20. 5

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9) = 100.

there were no significant differences. These groupings are shown in figure 3. There was no definite relationship between design of agitator and soil-removal index; agitators of different shapes sometimes performed similarly and those of similar design performed differently.

Results showed there was no correlation between soil-removing ability and water capacity of the washers. Of the 19 washers the one that used the most water in the wash period had the lowest index of soil removal. Figures for the others were scattered through the whole range in no definite pattern as shown in table 3.

WEIGHT OF LOAD

When giving the capacity of a washing machine in terms of weight of clothes, manufacturers usually recommend a load that will actually fill the washer tub—the heaviest load that can reasonably be washed.

Roberts (*20*) observed that "underloading of a machine affords better cleaning and less electric expense than overloading. It is better to use slightly smaller loads than the manufacturers' directions advise rather than larger." No supporting data were included in the report.

Potter (*19*) stated that "by stuffing the machine too solidly with clothes, agitation may be almost entirely stopped. Free movement of the cloth through the water is essential to effective washing." He

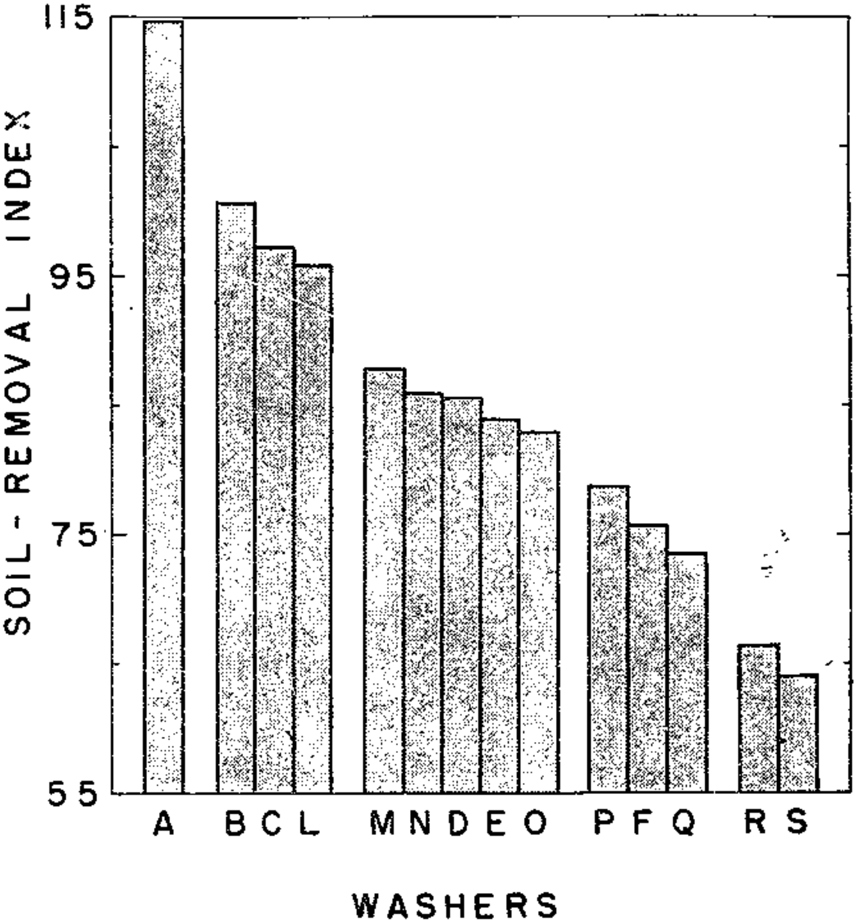

FIGURE 3.—Agitator washers grouped according to soil-removal indexes with 6-pound loads. (Soil-removing ability of Comparator=100.)

detected only slight differences in the soil-removing ability of a machine with 4-, 6-, or 8-pound loads, but found that 9-, 10-, and 12-pound loads greatly decreased the washer action. No data were given for loads over 8 pounds. Perkins (*17*) said, "Overloading the machine makes it impossible to get the clothes clean and also damages the motor." Experimental data were not given. McCordic (*11*) advised, "Avoid overloading as it may strain the motor."

To determine an optimum load for each of the 19 washers used in the study reported here, the load recommended by the manufacturer and at least 3 other loads—1, 2, and 3 pounds lighter—were washed. The experimental loads in 17 washers ranged from 5 to 10 pounds; in the other 2 washers, 3-pound loads also were washed. The general washing procedure, without detergent (p. 9), was followed, with the weight of the load the only variable.

A minimum of six replicates was made with each machine for each load. For some washers other tests with 6-pound loads contributed usable data, making more than 6 replicates. Additional replicates usually were made with machines that gave such high experimental errors that 6 replicates were insufficient to show that a mean difference of 5 points in soil-removal index was statistically significant at the 5-percent probability level.

Table 4 shows the number of replicates used for determining each of the mean indexes of soil removal and the figures defining the confidence interval at $t_{.05}$. The fiducial probability is 95 percent that the interval given includes the true mean for each load in each machine.

The data show a definite trend toward better soil removal as the weight of washer load was decreased from that given as the rated capacity (fig. 4).

Statistical analyses were made to test differences with the various loads in each washer. Among the loads in washers M and R there were significantly different results at $P=0.01$. In the other washers, except C, G, H, J, and N, the effects of the loads were significantly different at $P=0.05$. The five washers in which the indexes of soil removal for different loads were not significantly different represent all the types of washing mechanisms included in the study. (See table 1 for washer characteristics.)

Washers M and R, in which the differences were significant at $P=0.01$, were both agitators. The group in which load differences were significant at $P=0.05$ was made up of 2 cylinder and 10 agitator machines.

Since the load differences which were significant and those not significant were scattered among results for all washers, no one design may be said to allow heavier loading than others with less effect on the index of soil removal. In one cylinder machine the size of load made no significant difference in performance, whereas in the other cylinder machines the differences were significant.

Of the instances in which more than six replicates were needed to obtain the desired precision of estimates of the true means, a trend toward a greater number occurred with the heavier than with the lighter loads. This greater variability, together with poorer performance, showed that heavier loads gave less consistent and less satisfactory results than lighter ones.

It is concluded that, in general, a 6- or 7-pound load in a home washer will result in greater removal of soil and more uniform washing than heavier loads. There is no doubt a practical point beyond which the load should not be decreased if water and detergent necessary to do the cleaning job, and the time and effort of the person doing the laundry are to be used effectively.

With the heavier loads, as with the 6-pound load, there was no correlation of tub capacity with soil-removal index.

Effect of Heavy Loads on Electric Current Drawn.—Since strain on the motor would be reflected in an increase in amperage during the machine's operation, studies were made to determine the current needed for washers at various points in the washing operation under different-sized loads. The investigation included triplicate experiments with 6 nonautomatic and 10 automatic washers.

TABLE 4.—*Effect of weight of load on soil-removing ability of 19 washers*

Type of washer, mechanism, and load	Number of replicates	Soil-removal index[1] $\pm t_{.05}s_{\bar{x}}$
Automatic:		
A Agitator (tub capacity 14 gallons):		
3-pound load	11	123.5±3.5
5-pound load	6	109.3 3.6
6-pound load	29	114.8 3.0
7-pound load	6	97.0 3.5
8-pound load	19	104.8 3.3
B Agitator (tub capacity 13.5 gallons):		
6-pound load	9	100.8 1.5
7-pound load	6	96.7 3.2
8-pound load	8	93.7 3.2
9-pound load	6	91.0 2.3
C Agitator (tub capacity 15 gallons):		
5-pound load	6	97.1 4.4
6-pound load	10	97.3 3.4
7-pound load	10	94.1 3.4
8-pound load	12	92.2 3.5
D Agitator (tub capacity 16 gallons):		
3-pound load	6	97.4 4.0
5-pound load	12	92.5 5.7
6-pound load	6	85.6 4.0
7-pound load	12	85.5 5.4
8-pound load	6	77.9 2.2
9-pound load	21	76.2 3.9
E Agitator (tub capacity 19 gallons):		
6-pound load	10	83.9 2.8
7-pound load	6	80.7 3.5
8-pound load	6	74.1 1.8
9-pound load	12	71.7 2.8
F Agitator (tub capacity 17 gallons):		
6-pound load	12	75.9 4.8
7-pound load	12	68.4 3.5
8-pound load	12	65.2 4.0
9-pound load	12	61.6 4.3
G Modified agitator (tub capacity 11 gallons):		
5-pound load	16	78.8 2.3
6-pound load	6	78.6 2.7
7-pound load	19	79.1 3.5
8-pound load	12	77.0 3.9
H Agitating basket (tub capacity 7 gallons):		
5-pound load	6	82.9 2.8
6-pound load	13	86.1 3.0
7-pound load	8	85.0 3.1
8-pound load	7	88.4 3.8
I Cylinder (tub capacity 9 gallons):		
6-pound load	6	102.7 3.9
7-pound load	6	103.7 3.6
8-pound load	12	100.2 6.2
9-pound load	12	75.6 5.4
J Cylinder (tub capacity 6.5 gallons):		
6-pound load	6	90.3 4.1
7-pound load	7	91.9 3.8
8-pound load	12	92.3 3.7
9-pound load	8	87.0 3.1

See footnotes at end of table.

TABLE 4.—*Effect of weight of load on soil-removing ability of 19 washers*—Continued

Type of washer, mechanism, and load	Number of replicates	Soil-removal index [1] $\pm t_{.05}s_{\bar{x}}$
K Cylinder (tub capacity 10 gallons):		
6-pound load	7	88.3±3.9
7-pound load	12	85.0 3.7
8-pound load	6	81.1 2.6
9-pound load	6	78.5 3.1
10-pound load	9	75.2 2.9
Semiautomatic:		
L Agitator (tub capacity 11 gallons):		
5-pound load	6	89.6 2.5
6-pound load	12	95.8 3.4
7-pound load	6	86.8 3.5
8-pound load	6	84.9 2.0
Nonautomatic:		
M Agitator (tub capacity 20 gallons):		
5-pound load	6	88.5 3.3
6-pound load	24	87.9 1.0
7-pound load	6	85.9 3.3
8-pound load	6	85.2 2.3
N Agitator (tub capacity 19.5 gallons):		
5-pound load	6	84.6 2.8
6-pound load	6	86.0 2.7
7-pound load	8	84.3 3.3
8-pound load	6	81.4 2.8
O Agitator (tub capacity 16.5 gallons):		
5-pound load	8	82.6 3.2
6-pound load	6	83.2 3.4
7-pound load	6	80.7 2.3
8-pound load	11	73.0 2.5
P Agitator (tub capacity 16 gallons):		
5-pound load	6	82.2 2.5
6-pound load	6	78.9 2.6
7-pound load	8	76.0 3.2
8-pound load	12	71.4 3.3
Q Agitator (tub capacity 16 gallons):		
5-pound load	10	75.9 2.9
6-pound load	6	73.5 3.2
7-pound load	6	69.3 2.7
8-pound load	12	70.3 2.7
R Agitator (tub capacity 15 gallons):		
5-pound load	12	67.1 2.3
6-pound load	8	66.7 2.8
7-pound load	12	61.6 3.6
8-pound load	12	63.8 3.8
S Agitator (tub capacity 20.5 gallons):		
6-pound load	6	64.1 1.9
7-pound load	9	62.6 2.4
8-pound load	6	62.8 2.2
9-pound load	12	56.1 2.8

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9)=100. Mean soil-removal index $\pm(t_{.05}s_{\bar{x}})$ represents the 95-percent confidence interval for each mean.

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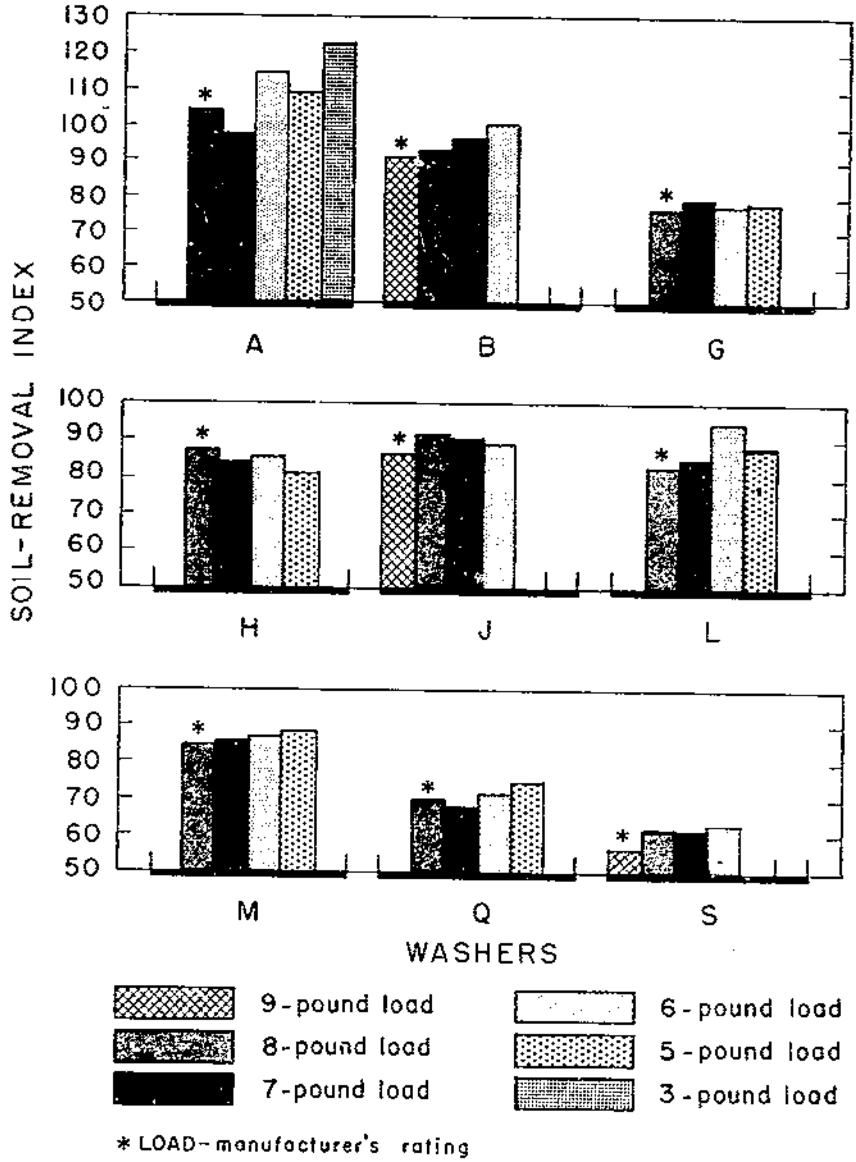

FIGURE 4.—Effect of decreasing weight of load on soil-removing ability of selected washers. (Soil-removing ability of Comparator=100.)

With nonautomatic agitator washers the procedure was as follows: The recording ammeter was connected into the circuit that furnished current to the machine, and the washer motor and time recorder were started. While the tub was being filled with water the motor was allowed to idle. After 5 minutes, or longer if the tub was not full at that time, the agitator was operated under each of the following conditions for a 5-minute period, during which the current demand was recorded: Without load; with a 6-pound load of bath towels: with 2 more pounds of bath towels; with another 2 pounds of bath towels; with the 10 pounds of bath towels while at the same time other wet bath towels from an adjacent tub were put through the wringer of the machine.

The agitator was then stopped and towels wrung from washer simultaneously with emptying of the tub.

In the six nonautomatic machines studied there were few peak pulls on the motor; that is, the current demand was relatively steady, and the high ammeter readings with different loads were not much greater than the low readings for the same action. In all six machines the highest current demand occurred when towels were being wrung from the laundry tubs while the agitator was working. The maximum increase of 0.26 amperes due to increased load occurred in only one test in one nonautomatic machine.

With automatic machines the 8-pound load was omitted because an increase of 2 pounds in the load had been found to make so little difference in the current demand of nonautomatic washers. Each of the 10 washers was allowed to operate through a complete cycle with 6-pound and 10-pound loads. Records were made of the current used for each step of the cycles.

For 7 of the 10 automatic washers, the addition of 4 pounds to a 6-pound load did not increase the current used. Washer G, which spins very rapidly in extracting water, used more current in the spinning of 10 pounds than 6, but not enough to make the spinning of a 10-pound load inadvisable. Washer H showed a material increase in use of current in all parts of its cycle with the larger load. Washer C was obviously overloaded with the 10-pound load. The motor gave off an offensive, overheated odor and the records showed a constant amperage fluctuation as the agitator worked to move the clothes through the water. Such a machine never should be used for washing more than the 8 pounds for which it was rated. Even the 8-pound load, used in a check test, caused some amperage fluctuation, but not as much as the 10-pound load.

The results indicate that in most washers, both automatic and nonautomatic, there is little danger of damage to motors through overloading with loads up to 10 pounds. Because washing results may not be acceptable and because some of the automatics were overloaded by a 10-pound load, loads above 8 pounds are not advised.

Soaking

The literature, both popular and scientific, commends soaking as a prewashing procedure. According to Carse and Jeffryes (*3*), "Soaking the clothes in clear water for 10 to 15 minutes removes the surface dirt, opens the meshes of the fabric, dissolves protein material such as is found on neck bands and cuffs, and removes some of the stains which would be set by hot, soapy water." Pond (*18*) made soaking the clothes an integral part of the laundry process as she outlined a procedure, specifying slightly warm, sudsy, soft water, and a 10- to 15-minute period.

Goodman (*8*) observed, "It has been found by experiment that clothes need not be soaked more than 15 to 20 minutes before washing.

The purpose of soaking clothing is to loosen the dirt so it may be removed in less time. Soaking clothes for long periods before washing causes dirt particles to swell in the fibers, thus becoming so ground into the fabric that they are difficult to remove. . . . It is usually best to put clothes to soak in cold water if they are to be left overnight, and warm water if they are to be soaked only for a short period. . . . Either hot water or soap will set the dirt in clothes and make it harder to remove." Morton (*15*) stated that white or fast-color clothes may be soaked in lukewarm soapy water for a short time or even for overnight. Covert (*5*) suggested that soaking clothes overnight or for a shorter time loosens dirt, saves time and wear.

Other recommendations are for two soapy washes, rather than a preliminary soaking treatment. None of these reports contain substantiating data.

Most of this advice was given before the days of automatic washers, and doubtless most of the soaking was assumed to be done in some container other than the washing machine. In most automatic washers it is possible to soak the clothes in the washer itself, either with or without agitation, and proceed to the regular washing process without any extra handling of the clothes. Soaking in nonautomatic machines necessitates handling clothes for water extraction and putting them back into the wash water, as well as an extra filling of the tub.

In the study reported here, experiments were conducted to compare the soil-removing ability of a washer in washing clothes without soaking, after soaking in clear water, and after soaking in a soap solution both nonagitated and agitated, for the same time and for different lengths of time.

Four separate series of experiments were made, 3 in automatic washer A, and 1 in nonautomatic washer Q. These machines were selected from among those having high and low indexes of soil removal.

In automatic washer A, the first series included washings without soaking, washings preceded by 15-minute nonagitated soaks in clear water, and by 5-, 10-, and 15-minute nonagitated soaks in soapy water. The second series included washings without soaking, and washings after 5-, 10-, and 15-minute agitated soapy soaks. The third series was confined to washings preceded by 15-minute soaks, an equal number agitated and nonagitated, with loads made up of naturally soiled clothes and clean clothes. The fourth was a nonagitated soaking series in nonautomatic washer Q. It included washings without soaking, with 5-, 10-, and 15-minute soapy soaks preceding the wash, and washings without soaking in which the amount of soap was increased by the amount used in the soaks.

In the soaking phase, temperature of water was 100° F. For soapy soaks a 0.05-percent soap solution was used.

Except for part of the third series in which clean clothes were used, loads consisted of 6 pounds of naturally soiled clothes with 5 artificially soiled samples pinned at random to various pieces in the load.

In both machines the water was extracted from the clothes after the soaking period by spinning for 2 minutes. In the automatic washer the clothes were removed from the tub before it was refilled in order to control the temperature of the water and to dissolve the soap before starting the washing.

For the washing phase a 0.10-percent soap solution was used at 140° F. when the clothes were put in the tubs for a 10-minute washing period, after which the regular cycle followed. In the nonautomatic machine the washing procedure for use with detergents (p. 10) was followed.

EFFECT OF WASHING WITHOUT SOAKING AND WITH NONAGITATED SOAKS.—The soil-removal index for washer A, which was 448 for washings without soak, was increased to 482 by a 15-minute nonagitated clear soak and to 511 by a 15-minute nonagitated soapy soak, as shown in table 5.

The mean amount of soil removed with a 15-minute nonagitated soak with soap was significantly greater at the $P=0.05$ level than the mean amount removed with a 15-minute nonagitated soak without soap.

The data for the series of tests with nonagitated soapy soaks in washer Q appear in table 6. A 15-minute nonagitated soapy soak increased the index of soil removal from 200 without soaking to 249.

In this machine experiments were made also to see whether washing without soaking, using an amount of soap equal to the combined amount for soaking and washing, would bring about the same results as using the extra soap for soaking. Compared with a soil-removal index of 200 for washing with 60 grams of soap with no soak, washing with 90 grams of soap with no soak gave an index of 219. A test-to-test comparison of the data for washing without soaking, with data

TABLE 5.—*Effect of washing without soaking and with a nonagitated clear and soapy soak on soil removal, washer A*

Replicate number	Soil removal index [1]				
	Without soak	With nonagitated soak			
		Without soap, 15 minutes	With soap		
			5 minutes	10 minutes	15 minutes
1	295.6	356.6	361.4	363.0	355.8
2	329.3	339.4	350.6	365.1	357.0
3	285.6	334.0	344.4	332.0	359.2
4	346.9	420.8	407.1	401.8	379.2
5	490.1	493.0	450.0	499.3	478.2
6	511.7	534.2	566.7	570.0	566.7
7	506.8	491.0	439.8	527.8	516.5
8	400.7	413.8	487.1	502.2	524.0
9	511.6	550.9	558.9	638.4	648.2
10	611.1	656.6	603.0	635.4	676.8
11	484.3	566.7	584.3	630.6	636.1
12	608.0	627.0	618.0	630.0	630.0
Mean	448.5	482.0	490.1	508.0	510.7

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9)=100.

TABLE 6.—*Effect on soil removal of dividing a specified amount of soap between nonagitated soak and wash compared with effect of using total amount of soap in wash, washer Q*

Replicate number	Soil-removal index [1]				
	Without soak; 60 gm. soap in wash	With nonagitated soak; 30 gm. soap in soak, 60 gm. soap in wash			Without soak; 90 gm. soap in wash
		5 minutes	10 minutes	15 minutes	
1	177. 1	172. 5	187. 4	167. 4	162. 0
2	184. 3	195. 9	221. 1	230. 7	190. 1
3	179. 7	231. 6	231. 4	243. 5	213. 6
4	195. 5	237. 4	261. 0	249. 8	222. 8
5	218. 8	247. 3	229. 8	279. 4	245. 2
6	162. 8	211. 4	215. 0	232. 0	202. 9
7	215. 3	236. 0	238. 3	257. 3	208. 3
8	212. 4	239. 9	220. 6	249. 1	239. 9
9	214. 3	222. 8	274. 3	286. 0	243. 0
10	188. 8	227. 0	253. 1	286. 8	234. 9
11	248. 9	217. 3	257. 5	252. 6	243. 2
Mean	199. 8	22[illegible]. 7	235. 4	248. 6	218. 7

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9)=100.

obtained with 30 grams of soap in the soak and 60 grams in the wash, indicates that in general it is more satisfactory to use the extra soap for soaking for even as short a period as 5 minutes than to use it in the wash.

EFFECT OF NONAGITATED AND AGITATED SOAPY SOAKS.—An experiment to compare directly the effect of soaking with and without agitation was done in automatic washer A. Samples for this experiment were from four strips of identically soiled material. In one part of the experiment the load was made up of naturally soiled clothes, plus the artificially soiled samples. In the other part, a clean load, except for the samples, was soaked and washed in exactly the same manner. Results of both test conditions are given in table 7.

Statistically, the treatment differences, whether clean or naturally soiled clothes made up the load, were highly significant, the agitated soak being much more effective than the nonagitated. Analysis showed no significant difference between the strips. The coefficients of variation show that washing artificially soiled samples attached to clean materials as load gave more consistent performance of the washer than washing the samples with naturally soiled clothes. The results give justification for recommending an agitated soak over nonagitated, where such method is practical.

EFFECT OF DIFFERENT SOAKING TIMES.—Results in the series of tests in washer A to determine the effect of an agitated, soapy warm soak for different lengths of time are given in table 8. In analyzing these data, the soil-removal indexes for the replicates given for each soaking period were averaged and the figure compared with the average

TABLE 7.—*Effect of nonagitated and agitated soaks, with clean and naturally soiled loads, on soil removal, washer A*

Load and sample strip	Soil-removal index,[1] with 15-minute soapy soak—	
	Without agitation	With agitation
Naturally soiled clothes with artificially soiled samples from—		
Strip A	158.4	188.6
	150.8	198.6
	135.0	200.5
Strip B	148.6	181.5
	160.0	186.3
	117.3	189.8
Mean	145.0	190.9
Coefficient of variation	11.2	3.8
Clean cotton squares with artifically soiled samples from—		
Strip C	188.2	235.0
	207.0	232.7
	192.9	240.5
Strip D	180.9	239.1
	194.4	225.8
	187.2	236.8
Mean	191.8	235.0
Coefficient of variation	4.6	2.2

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9) = 100.

of the indexes for the same replicates in tests without soak; for example, in determining the effect of a 5-minute soak, only replicates 2, 3, and 5 were used. On this basis, compared with a soil-removal index of 383 when no soaking was used, the index for a 5-minute soak was 427, an increase of 44; a 10-minute soak gave a 60-point increase; a 15-minute soak, a 94-point increase; and a 20-minute soak, a 104-point increase.

Although this comparison makes it appear that a 20-minute soak is more effective than the shorter soak, an inspection of the data for the paired 15- and 20-minute soaks shows that in only 1 of the 4 pairs (replicate 6) was the index improved by increasing the time to 20 minutes.

There was a statistically significant (P=0.01) curvilinear regression of change in soil-removal index on the length of time of nonagitated soapy soaking in washer A. (See data, table 5.) There was a large increase between 0 and 5 minutes; however the rate of increase diminished as the soaking time was lengthened from 5 to 15 minutes.

TABLE 8.—*Effect of a 5-, 10-, 15-, and 20-minute agitated soapy soak on soil removal, washer A*

Replicate number	Soil-removal index[1]				
	Without soak	With agitated soak with soap			
		5 minutes	10 minutes	15 minutes	20 minutes
1	433.6	----------	501.7	----------	----------
2	429.4	461.3	478.2	----------	----------
3	473.2	525.5	544.9	572.9	----------
4	316.5	----------	465.2	475.5	436.6
5	245.8	295.0	----------	371.2	368.6
6	287.9	----------	306.0	365.8	381.6
7	240.2	----------	248.5	286.8	----------
8	273.6	----------	303.2	300.8	----------
9	258.0	----------	305.7	348.2	----------
10	262.0	----------	359.0	385.5	342.2

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9) = 100.

The regression equation obtained was $Y=44.90+4.94X-0.97X^2$, where X represented the soaking time in units of 5 minutes.

The curvilinear regression is a reflection of the effectiveness of washer A in removing soil from clothes, bearing out the results of other tests in the study, which indicated this washer's superior performance.

In washer Q (less efficient than washer A in other soil-removal tests) there was a statistically significant ($P=0.01$) linear increase in the amount of soil removed as nonagitated soaking was increased from 0 to 15 minutes. (See table 6.) On the average, the soil-removal index increase was 3.2 for each 1-minute increase in the soaking time.

TEMPERATURE OF WATER FOR WASHING

In the literature, different temperatures of water are reported as optimum for washing. Roberts (*20*) stated that the recommended temperature for cotton and linen was 140° to 160° F. Snyder and Brunig (*21*) used several combinations of soil and washing temperatures, and stated, "It is probable that, in general, washing temperatures used in common practice are too high." They pointed out that high temperatures may be used if clothes have been soaked. Pond (*18*) recommended 120° F. for washing without soaking, but 140° to 150° if clothes had been soaked in lukewarm water. Potter (*19*) found that 160° did a better cleaning job than lower temperatures, and recommended 150° at least for beginning the washing.

In the experiments reported here to determine the relative effectiveness of water of different temperatures in removing soil from artificially soiled samples, only the Comparator washer was used. Three-pound loads of clean muslin squares, with 10 soiled samples in each, were washed for 10 minutes in water of 5 temperatures, ranging from 120° to 160° F., with 10° differences. No temperature higher than 160° was used, as few models of water heaters are designed to deliver water hotter than that to a washer; higher temperatures are less economical to maintain in a water heater, are increasingly hard on washer hoses and valves, and dangerous to those using the water supply.

One series of experiments was made with no detergent; in a second series a 0.02-percent soap solution was used (an unbuilt flake soap described by Furry (7) as "soap 1"). In the former, water was extracted from the load in a spinner tub at the end of the 10-minute wash period. When soap was used, the 10-minute washing was followed by two 3-minute rinses in 100° F. water, with water extraction in a spinner tub after each process.

Results of the experiments on water temperature appear in table 9. Since only the Comparator washer was used, results are given as reflectance changes. In experiments without soap there was a significant average linear increase in the amount of soil removed as the temperature of the water was increased from 120° to 160° F. The average reflectance increase was 0.0486 points per degree increase in water temperature. The regression equation was $Y=9.954+0.0486X$, where X was the temperature change in degrees.

Results of the experiments with soap show a significant curvilinear regression of the amount of soil removed on the temperature of the water. The increase in the average amount of soil removed was small when the temperature was increased from 120° to 130° and from 150° to 160° F. A larger increase per degree of temperature was obtained between 130° and 150°, the greatest occurring between 130° and 140°. The regression equation was $Y=14.515-2.109X+1.015X^2-0.116X^3$, where X stands for the increase above 120° expressed in units of 10°.

These results show that as the temperature of the wash water is increased up to 160° F. more soil is removed.

TABLE 9. *Effect of temperature of washing water on soil removal*

Washing procedure and temperature of wash water	Reflectance increase[1]		
	Replicate 1	Replicate 2	Replicate 3
10 minutes without soap; no rinse:			
120° F	12.7	9.5	9.2
130° F	12.9	9.5	10.2
140° F	13.3	10.2	10.8
150° F	13.9	10.6	11.3
160° F	14.4	10.8	11.8
10 minutes with built flake soap; two 3-minute rinses at 100° F.:			
120° F	14.0	12.9	13.1
130° F	13.6	13.4	13.0
140° F	14.7	14.2	14.0
150° F	15.3	14.7	14.4
160° F	14.8	15.2	14.7

[1] Each figure is the mean difference between reflectance readings of 10 samples before and after washing in Comparator washer.

Detergent Concentration in Hard Water

Because hard water is a problem in many sections of the country, an experiment was conducted to determine the effectiveness of different types of detergents in water of 300 p. p. m. hardness. Tests were made with 3 concentrations of each of 3 detergents specified for heavy duty laundering (a built low-sudsing syndet,[9] a built high-sudsing syndet, and a built soap).

For this work automatic washer C and nonautomatics N and S were used. These were agitator machines having high, medium, and low indexes of soil removal (see table 3).

Detergent concentrations were 0.2, 0.3, and 0.4 percent. Water hardness of approximately 300 p. p. m. was obtained by adding 0.736 grams $MgCl_2.6H_2O$ and 1.133 grams $CaCl_2.2H_2O$ to each gallon of tap water.

From each of 6 strips of soiled cloth, 100 samples were chosen in matching sets of 10 for each day's test. Each of three detergent concentrations was replicated twice in each washer. The combination of detergent concentration, kind of detergent, and washer was determined by use of the incomplete block plan of Cochran and Cox (*4*), designed for two replicates. Samples were attached to pieces of naturally soiled clothes assembled in 6-pound loads and washed 10 minutes in 140° F. water, as outlined in the procedure for washing with detergents, page 10.

The mean indexes of soil removal for two replicates are shown in figure 5. Statistical analysis showed that machines, detergents, and concentrations all produced highly significant effects on the washing results. There was a trend for indexes to increase as the percentage of detergent was increased, but not proportionately.

Performance of the three machines ranked in general as they did without detergents: Washer C removed more soil than N (except with detergent B, when results with 0.2- and 0.3-percent concentrations were better in washer N), and N more than S. The least total detergent was provided for the washing in washer C, since it holds the smallest amount of water, yet it did the best washing job. This agrees with the findings reported on page 11 that there was no positive correlation between quantity of water a machine holds and its index of soil removal.

In all 3 washers with detergent A, a low-sudsing built syndet, an increase from 0.2- to 0.3-percent concentration resulted in an increase in soil-removal index. The 0.4-percent solution was slightly more effective than the 0.3-percent in washers A and N, but no more effective in washer S.

In all 3 washers results were slightly better with detergent B, the built, high-sudsing syndet, when 0.3-percent concentration was used rather than 0.2-percent. Two of the washers showed lower indexes with a 0.4-percent solution of the detergent than with either the 0.2- or 0.3-percent solution. Evidently in these washers a 0.3-percent solution of this high-sudsing syndet was sufficient and an added amount less effective.

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[9] Synthetic detergent.

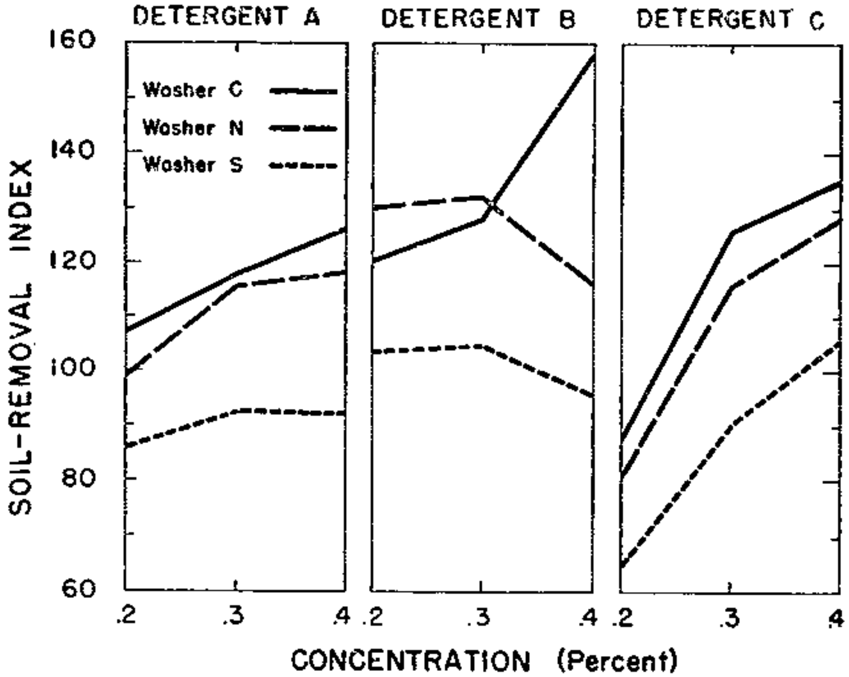

FIGURE 5.—Soil-removal indexes of 3 washers with 3 concentrations of 3 detergents in water of 300 p. p. m. hardness. (Soil-removing ability of Comparator=100.)

These results with synthetic detergents agree in general with the findings of Furry and associates (7), who reported a similar leveling effect on soil removal by increased concentrations of synthetic detergents in hard water.

In all three washers, the higher the concentration of C, the built soap, the greater was the amount of soil removed. The increase in soil removal was greater between the 0.2- and 0.3-percent concentrations than between the 0.3- and 0.4-percent. This indicated that at concentrations between 0.2- and 0.3-percent the soap counteracted the hardness of the water and became effective as a detergent.

Although the detergents were all designed for heavy-duty laundering, the data show that, as used in the 3 washers, they differed markedly in effectiveness in water of 300 p. p. m. hardness. They differed also in volume needed for a solution of specified concentration. For example, to obtain a 0.4-percent concentration, washer A took 1¼ cups of syndet A, 2¾ cups of soap C, and 3 cups of syndet B.

The findings emphasize the necessity of suiting the type and amount of detergent to the volume and hardness of the water, points often not taken into account in directions for use of machines and detergents.

Method of Water Extraction

Potter (*19*) claimed some cleaning from each of the two chief methods of water extraction, wringing and spinning, used in household washers, in this statement, "The wringing of the clothes each time they pass from one water to the next, has an appreciable cleaning effect. The severe pressure of the wringer rolls or the centrifugal force of the basket dryer are types of agitation that aid in forcing water through the fabric, thus removing dirt." Lovell and associates (*10*) gave the wringer credit for greater soil removal than the spinner.

In the present study of the comparative cleaning action of the 2 methods of water extraction, 6 wringers and 6 centrifugal extractors of the household washers were used. Tests were done in triplicate.

Thirty artificially soiled samples (3 matching sets of 10) were pinned to clean muslin squares and washed at one time in a 6-pound load in the Comparator machine. One set was marked for wringer extraction, one for the spinner, and one for drying on glass without water extraction. The washing time was 5 minutes, in 140° F. softened water. At the end of the washing period, squares were sorted for extraction as they were taken from the water.

The wringers were set at the highest tension settings; spinners were operated for 3 minutes. The total reflectance change of each set of 10 samples was related to the change in the matching 10 samples which dried without extraction.

In 26 of the 36 sets of samples the indexes of soil removal were over 100, showing that some removal of soil took place during wringing and spinning, although the figures are quite variable (table 10). Statistical analysis showed no significant difference between the two methods of water extraction in soil-removing ability.

Length of Wash Period

Another question in the home laundering procedure is length of washing time. Roberts (*20*) recommended agitation for 15 minutes or longer. Pond (*18*) said that 10 minutes was sufficient for the average load. Quoting from Potter (*19*), "At least one manufacturer has stated that his machine will wash clothes in 5 minutes. Many housewives insist that one-half hour of washing is necessary. Probably somewhere between these two time periods will be found the correct one." His study revealed that most of the cleaning in laundering was accomplished during the first 5 to 10 minutes, in tests which took washings through a 30-minute period, with removal of samples at 5-minute intervals. Mack (*12*) observed that there is an optimum time for washing. In the 1-gallon launderometer containers in which her tests were done, this optimum was 20 minutes. She explained that soil, once removed, must be held in suspension or it will be reprecipitated on the fabrics; too long agitation can cause this redeposition of the soil.

To determine the relationship of length of washing time to soil removal, an experiment was conducted in which washing periods of 5, 10, 15, and 20 minutes were used. Six-pound loads of clean cotton squares with 10 artificially soiled samples attached were washed in 6 of the machines for 2 or more different periods. All were agitator

TABLE 10.—*Effect of 2 methods of water extraction on soil removal*

Method of extraction, washer,[1] and replicate number	Soil-removal index [2]	Method of extraction, washer,[1] and replicate number	Soil-removal index [2]
Wringer:		Spinner:	
M:		F:	
1	107.5	1	90.9
2	112.2	2	100.8
3	104.0	3	111.5
N:		G:	
1	103.9	1	101.5
2	102.1	2	97.6
3	115.9	3	122.8
O:		J:	
1	103.8	1	106.8
2	92.0	2	97.9
3	100.3	3	103.7
P:		K:	
1	105.9	1	96.9
2	92.8	2	92.8
3	117.4	3	107.1
R:		L:	
1	112.0	1	109.6
2	106.6	2	93.1
3	110.1	3	107.5
S:		Q:	
1	100.4	1	93.2
2	101.6	2	94.2
3	103.3	3	104.4
Mean	105.1	Mean	101.8

[1] Used for extraction only. All samples washed in Comparator.
[2] Soil-removal value derived from samples dried without water extraction=100.

machines; 4 were nonautomatic and 2 automatic. Washing was done in 140° F. softened water without detergent and without rinsing.

The data in table 11 show substantial increases in soil-removal indexes as washing time was increased by 5-minute intervals up to 20 minutes, though the rate of increase in the indexes was not the same for all washers. The greatest increase occurred between 5 and 10 minutes.

Results are shown graphically in figure 6.

TEMPERATURE OF WATER FOR RINSING

Almost without exception the literature on laundering recommends warm or hot water for the first rinse. Roberts (*20*) recommended a very hot first rinse and a second cool rinse, and Dowdy (*6*) one hot, one lukewarm, and one cold rinse. Snyder and Brunig (*21*) warned against a cold rinse. Pond (*18*) advised two or three rinses, the first at least 120° F., the second only slightly warm. Goodman (*8*) suggested the first rinse be the same temperature as the wash water, then a cool rinse, and a third, cold rinse. Morton (*15*) agreed on using warm water for the first rinse "to remove all soap from the fabrics" and suggested a second rinse as desirable if one has an ample water supply.

TABLE 11.—*Effect of length of washing period on soil removal*

Type of washer and mechanism, washing period	Number of replicates	Soil-removal index [1] $\pm t_{.05}s_{\bar{x}}$	
Automatic:			
A Agitator:			
10 minutes	29	114.8	±3.0
20 minutes	3	145.2	9.4
C Agitator:			
5 minutes	6	71.0	3.8
10 minutes	10	97.3	3.4
20 minutes	6	130.1	6.7
Nonautomatic:			
M Agitator:			
10 minutes	21	87.9	1.0
15 minutes	18	100.3	1.3
20 minutes	17	112.9	1.6
Q Agitator:			
10 minutes	6	73.5	3.2
20 minutes	9	90.6	3.3
R Agitator:			
5 minutes	6	43.9	3.3
10 minutes	8	66.7	2.8
15 minutes	14	70.9	1.9
20 minutes	14	80.1	2.3
S Agitator:			
10 minutes	6	64.1	1.9
15 minutes	17	73.0	1.2
20 minutes	17	73.2	1.6

[1] Soil-removing ability of Comparator with standard washing procedure (p. 9) = 100. Soil-removal index $\pm(t_{.05}s_{\bar{x}})$ represents the 95-percent confidence interval for each mean.

In the study reported here, two series of experiments were carried on to compare the effect of warm and cold rinses. In one series, two automatic washers were used, one which provided a warm rinse, and one which provided a cold rinse. The machine used in the other series was an automatic in which it was possible to select the desired rinsing temperature; in this series the effect of ironing was also studied. The change in light reflectance of white samples was used to measure rinsing effectiveness.

The agitator-type automatic washers used in the first series were washer F, which rinsed with several warm sprays and one deep agitated rinse in warm (100° F.) water, and washer A, which rinsed with a warm spray followed by a cold (approximately 60° F.) agitated overflow rinse. (See table 1 for cycle descriptions.)

Samples for each series were five 8-inch squares of the same white desized cotton sheeting used in other phases of the study. Readings of light reflectance were made at each corner of each sample before the first washing. One sample was retained without washing.

Six pounds of naturally soiled clothes, washable in hot water, and the four test samples made up the load. Each sample was attached with two pins to some piece of the load. Washers were filled to the water line with 140° F. water, a granulated built soap was added (0.10-percent soap solution in washer A, 0.16-percent soap solution

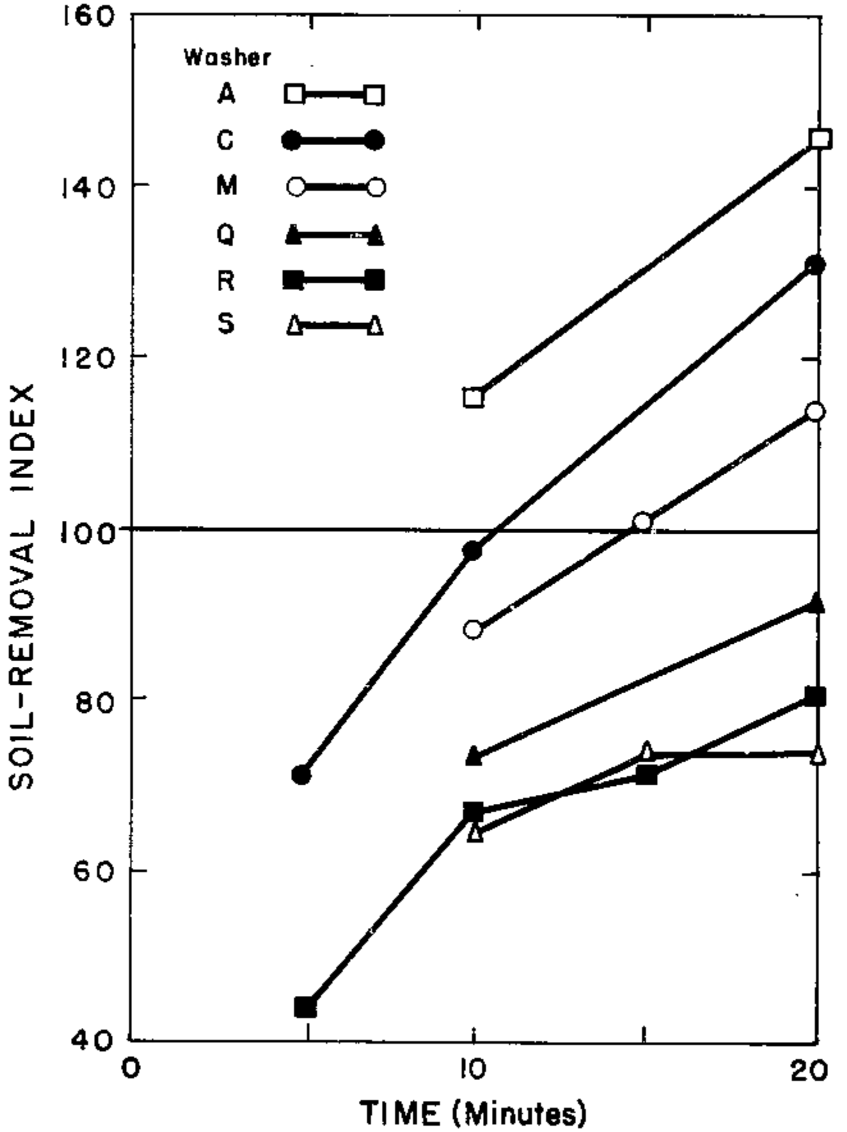

FIGURE 6.—Effect of washing time on soil-removing ability of 6 washers with 6-pound loads. (Soil-removing ability of Comparator=100.)

in washer F), and the clothes were washed for 10 minutes. At the end of the washing period the washer was allowed to continue its operation through the cycle.

The washed samples were removed and placed flat on glass to dry. After 25 washings sample reflectances were read at each of the 4 corners. The porcelain-enameled square reflecting 78.8 percent of incident light was used for standardizing the reflectometer and for backing the samples during reading.

Results of the first group of washings in the machine with the deep rinse in cold water showed a 1.8-point mean decrease in sample reflectance. This change, although statistically significant, was so small that it could not be detected by visual comparison. A second series of tests in the same machine showed a slightly greater mean decrease, 3.0 points, with no added effect when the samples were washed an additional 25 times. Evidently this cold water rinse was effective in removing the soap, or at least effective enough to give results after 50 washings that did not show a graying detectable by the eye. In the washer in which a warm deep rinse followed a spray rinse, a similar series of 25 washings showed a 2.8-point mean decrease in reflectance, which was also statistically significant, but not detectable by the eye. The reflectance of untreated samples remained practically the same in the experiments.

The second series of experiments with warm and cold rinses was made in washer B, in which the water temperature for rinsing as well as for washing could be selected as hot, medium, or cold.

For test samples twenty-two 8- by 8-inch pieces of white desized cotton sheeting were used, 10 for each rinse temperature, and 2 to retain as controls. Readings of samples, kind and weight of load, and water temperature for washing were similar to the previous series. A 0.1-percent solution of a built soap in 140° F. water was used for the wash. Washing time was controlled as nearly as possible at 10 minutes; exact control was not possible. The washer was then allowed to finish its cycle with either a warm (approximately 100° F.) or cold (approximately 60° F.) rinse as the experiment required.

Samples were unpinned from the load and five of each set were dried on a rack before they were washed again. The other five, used to test the effect of ironing, were wrapped in plastic sheets so they would not lose moisture, then ironed dry on a flatplate ironer. Samples from the warm and cold rinses were ironed at the same time. The ironer was preheated 15 minutes on the "cotton" setting for ironing each set of 10 samples, and then the heat was turned off. Each sample was ironed for 15 seconds on each side; the ironing surface was large enough for 3 samples to be ironed at one time. This procedure was carried out for 50 tests with each temperature rinse. Reflectance readings of the test samples were made after 5, 25, and 50 washings. Results are given in table 12.

All test samples reflected less light with repeated washing and rinsing and still less with ironing. After 50 washings, the unironed samples that had been rinsed in warm water had decreased least in reflectance, a mean of 3.7 points. The ironed samples had changed 5.4 points. The unironed and ironed samples from the cold rinse had changed 4.4 and 6.2 points, respectively. Untreated samples remained unchanged.

A statistical analysis of the reflectance changes of the individual samples after 50 washings and rinsings showed the differences resulting from rinsing treatments to be highly significant. The close agreement of reflectance change in all the samples within any one treatment may account for this in part. Despite the fact that statistically there were highly significant differences among the reflectance changes resulting from these four methods of treating the samples, no differences in the appearance of the samples were visible.

TABLE 12.—*Effect of warm and cold rinses on whiteness of samples, washer B*

Conditions	Reflectance [1]			
	Before washing	After 5 washings	After 25 washings	After 50 washings
Warm rinse, 100° F.; not ironed	85.2	84.0	82.6	81.5
Cold rinse, 60° F.; not ironed	85.4	83.9	81.3	81.0
Warm rinse, 100° F.; ironed without drying	85.4	84.0	82.1	80.0
Cold rinse, 60° F.; ironed without drying	85.2	83.8	80.2	79.0

[1] Figures are means of 20 readings, at 4 different positions on each of 5 samples.

In these 2 series of rinsing tests, involving 3 automatic washers, either a warm or cold deep-water agitated rinse gave satisfactory results. Objective measurements of light reflectance showed differences that were statistically significant in favor of the warm rinse, but not apparent to the eye.

EFFECT OF WASHER ACTION AND METHOD OF WATER EXTRACTION ON DIMENSIONAL CHANGE AND BURSTING OR BREAKING STRENGTH OF CERTAIN LINGERIE FABRICS

One of the frequent questions from homemakers is whether one type of washer will cause more wear on fabrics than another.

Snyder and Brunig (*21*) washed samples of Indian Head for the same length of time in eight machines, representing gyrator, cylinder, vacuum, and dolly actions. Of the washers tested, the dolly machine caused the greatest loss in fabric strength; there was considerable variation in data obtained. Potter (*19*) observed progressive losses in tensile strength of sheets washed 100 times with home laundry equipment in the laboratory. He made no attempt to compare results of different home washer actions.

Experiments here reported were conducted to determine the changes in several lingerie fabrics caused by (1) four different washing actions—agitator, cylinder, agitating basket, and modified agitator, and (2) three methods of water extraction—wringing, spinning, and pressing between bath towels.

EXPERIMENTAL PROCEDURES

For studies of the effect on dimensional changes and on bursting or breaking strength, five lingerie fabrics were used: Acetate-viscose satin and crepe, acetate tricot, and nylon crepe and tricot.

Samples varied in size from 18 to 21½ inches square, depending on the width of the bolt from which they were cut. After each square was hemmed and numbered and before it was measured and its strength determined, it was placed on a plastic screen tray and left for 2 days in the conditioning room which was controlled at a temperature of 70° F. and a relative humidity of 65 percent. In the center of each sample, a 10-inch square was marked for dimensional measurements.

Samples of each fabric were prepared and randomized for 3 replicates for each of 6 washers, 2 nonautomatics and 4 automatics. A 6-pound load was made up of the experimental samples of each fabric and additional pieces of the 5 kinds of fabrics. Each load was washed 10 minutes in 100° F. water without a detergent.

For determination of the effect of method of water extraction, samples washed in the same load were taken out at the end of the 10-minute wash period, and water was extracted by each of the 3 methods—wringing, spinning, and pressing between towels.

For analysis of changes caused by washer action, samples in the nonautomatic washers were given two agitated 100° F. rinses; after each rinse, water was extracted with a wringer. In the automatic washers the normal cycle of rinsing and spinner water extraction followed the wash period.

In both these series of tests, samples were dried on plastic screen trays at room temperature, then conditioned in the controlled temperature and humidity room before physical measurements were made. As samples were drawn for analysis of treatment effects after 10 and 20 washings, like swatches of the same fabrics were added to the load to keep it constant in weight.

Raveled strip breaking strengths were measured in accordance with procedures outlined in A. S. T. M. D 39-49 (*1*). Six warp and 6 filling determinations were made on each sample of 3 replicates, making 18 determinations for calculating each mean used in the analysis of data. Bursting strengths of knitted fabrics were measured in accordance with procedures outlined in A. S. T. M. D 231-46 (*1*).

Dimensional measurements of the woven fabrics were made after samples were pressed under tension on a machine developed for that purpose by the United States Testing Company. The knitted fabrics were measured under water by means of a divider.

Results

Breaking strength indexes of the woven materials and bursting strengths of the knitted fabrics after washing showed that the six washers differed to a significant degree in their effect as measured by fabric strength (tables 13 and 14). However, no one machine consistently caused more change than another; the differences were not consistent from fabric to fabric or even from warp to filling in the same fabric.

There was a trend toward lower breaking or bursting strengths as the number of washings was increased in the different washers. Usually the first 20 washings caused a greater decrease in strength than did the last 30.

TABLE 13.—*Mean breaking-strength indexes of woven fabrics washed in different washers*

Type of washer and mechanism	Warp breaking-strength index [1] after specified number of washings				Filling breaking-strength index [1] after specified number of washings			
	1	10	20	50	1	10	20	50
	Acetate-viscose crepe							
Automatic:								
F Agitator	0.15	0.14	0.14	0.12	0.30	0.30	0.31	0.30
G Modified agitator	.15	.14	.13	.12	.30	.31	.30	.30
H Agitating basket	.16	.14	.13	.13	.30	.31	.32	.32
J Cylinder	.15	.13	.13	.11	.30	.31	.30	.31
Nonautomatic:								
M Agitator	.16	.14	.13	.11	.28	.28	.28	.29
O Agitator	.14	.12	.11	.10	.29	.29	.28	.30
	Acetate-viscose satin							
Automatic:								
F Agitator	0.15	0.15	0.14	0.14	0.22	0.22	0.21	0.20
G Modified agitator	.14	.14	.13	.14	.21	.22	.21	.20
H Agitating basket	.15	.15	.16	.15	.23	.22	.22	.22
J Cylinder	.15	.14	.14	.13	.22	.21	.21	.20
Nonautomatic:								
M Agitator	.14	.14	.14	.13	.23	.20	.20	.22
O Agitator	.16	.14	.13	.12	.22	.21	.21	.21
	Nylon crepe							
Automatic:								
F Agitator	0.43	0.42	0.42	0.41	0.72	0.73	0.71	0.71
G Modified agitator	.44	.42	.39	.43	.71	.70	.68	.72
H Agitating basket	.42	.42	.42	.42	.70	.69	.70	.69
J Cylinder	.43	.42	.41	.43	.72	.71	.68	.72
Nonautomatic:								
M Agitator	.41	.40	.40	.38	.70	.72	.69	.71
O Agitator	.41	.39	.38	.37	.68	.70	.68	.69

[1] Breaking strength divided by yarns per inch. Mean of at least 18 measurements.

TABLE 14.—*Mean bursting strength of knitted fabrics washed in differen washers*

Type of washer and mechanism	Bursting strength in pounds per square inch after specified number of washings[1]			
	1	10	20	50
	Nylon tricot			
Automatic:				
F Agitator	166. 9	163. 1	155. 9	156. 3
G Modified agitator	170. 4	162. 7	161. 4	160. 2
H Agitating basket	169. 2	164. 2	166. 0	159. 2
J Cylinder	162. 9	157. 6	156. 5	155. 2
Nonautomatic:				
M Agitator	165. 8	166. 6	167. 4	164. 5
O Agitator	170. 8	169. 4	168. 5	168. 0
	Acetate tricot			
Automatic:				
F Agitator	33. 1	33. 3	32. 6	33. 3
G Modified agitator	34. 7	35. 7	36. 0	35. 2
H Agitating basket	33. 2	33. 3	32. 5	33. 5
J Cylinder	33. 4	34. 3	34. 3	34. 6
Nonautomatic:				
M Agitator	38. 2	37. 8	37. 7	36. 1
O Agitator	36. 0	36. 1	35. 9	35. 6

[1] Mean of 27 readings, 9 for each sample, 3 replicates.

Table 15 gives the data for dimensional measurements of fabrics washed 1, 10, 20, and 50 times. Analysis showed significant differences in both the washers and the number of washings. No one machine ranked consistently in its relative effect on shrinkage or stretch. In general, a greater amount of change occurred in the first 20 washings than in the last 30.

In the investigation of the effect of three methods of water extraction, the differences among the mean changes in strength and dimensions resulting from the wringer, spinner, and towel methods of extraction were not statistically significant. Differences among values for each method and each number of washings were small. These data have been summarized in detail by Marron (*13*).

No type of washer action studied can be said to cause more changes than another in the lingerie fabrics laundered 50 times. Neither can any of the three methods of water extraction be said to cause more changes than another.

TABLE 15.—*Mean dimensional measurements after washing, of fabric areas originally 10 inches square*

Type of washer and mechanism	Length after specified number of washings [1]				Width after specified number of washings [1]			
	1	10	20	50	1	10	20	50
	Acetate-viscose crepe							
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Automatic:								
F Agitator	9.92	9.84	9.81	9.74	9.94	9.94	9.90	9.95
G Modified agitator	9.91	9.84	9.82	9.80	9.95	9.90	9.91	9.89
H Agitating basket	9.89	9.83	9.77	9.77	9.97	9.92	9.94	9.93
J Cylinder	9.87	9.83	9.77	9.61	9.93	9.91	9.92	9.90
Nonautomatic:								
M Agitator	9.92	9.99	9.92	9.83	10.00	9.90	9.92	9.92
O Agitator	9.94	9.96	9.96	10.01	10.03	10.02	9.98	9.99
	Acetate-viscose satin							
Automatic:								
F Agitator	9.84	9.79	9.74	9.78	9.87	9.90	9.86	9.88
G Modified agitator	9.80	9.78	9.73	9.75	9.92	9.89	9.89	9.88
H Agitating basket	9.82	9.81	9.80	9.81	9.92	9.91	9.91	9.87
J Cylinder	9.82	9.76	9.78	9.73	9.88	9.89	9.86	9.85
Nonautomatic:								
M Agitator	9.84	9.82	9.79	9.71	9.96	9.96	9.93	9.93
O Agitator	9.88	9.87	9.81	9.77	9.98	9.93	9.97	9.96
	Nylon crepe							
Automatic:								
F Agitator	9.98	9.91	9.91	9.92	10.07	10.04	10.05	10.06
G Modified agitator	9.96	9.91	9.83	9.82	10.04	10.03	9.80	9.77
H Agitating basket	9.96	9.93	9.92	9.92	10.06	10.05	10.04	10.04
J Cylinder	9.97	9.93	9.84	9.78	10.04	10.07	9.83	9.79
Nonautomatic:								
M Agitator	9.96	9.93	9.91	9.87	10.08	10.07	10.07	10.06
O Agitator	9.99	9.93	9.93	9.91	10.11	10.09	10.08	10.07
	Nylon tricot							
Automatic:								
F Agitator	9.89	9.84	9.92	9.85	9.89	9.83	9.77	9.77
G Modified agitator	9.88	9.87	9.91	9.88	9.88	9.84	10.04	10.05
H Agitating basket	9.98	9.95	9.88	9.85	9.89	9.82	9.82	9.78
J Cylinder	9.93	9.89	9.91	9.89	9.85	9.85	10.03	10.03
Nonautomatic:								
M Agitator	9.96	9.91	9.85	9.83	9.99	9.78	9.84	9.79
O Agitator	10.00	9.97	9.97	9.83	9.92	10.05	9.87	9.78
	Acetate tricot							
Automatic:								
F Agitator	9.81	9.59	9.54	9.53	8.48	8.49	8.32	8.11
G Modified agitator	9.69	9.56	9.58	9.35	8.50	8.39	8.22	8.64
H Agitating basket	9.76	9.63	9.61	9.59	8.75	8.42	8.26	8.16
J Cylinder	9.74	9.61	9.59	9.41	8.45	8.07	8.19	7.91
Nonautomatic:								
M Agitator	9.75	9.54	9.45	8.75	8.97	9.30	9.60	11.06
O Agitator	9.77	9.69	9.24	8.34	8.80	8.97	10.10	12.05

[1] Mean of 9 measurements.

SUMMARY OF RESULTS

This bulletin reports a study of the operating characteristics of automatic, nonautomatic, and semiautomatic washers of different designs, and of factors in the washing process affecting their ability to remove soil. It supplies technical information for use in the preparation of guides to consumer selection and care and use of home washing machines and for guidance of manufacturers in the development of washer designs. Some findings of this research as related to design factors were:

1. Of the three types of washing machines studied—automatic, nonautomatic, and semiautomatic—no one type was consistently superior in soil removal. The study included 11 automatic washers, 7 nonautomatics, and 1 semiautomatic.

2. No one type of washing mechanism was consistently superior in soil removal as judged by results obtained in 14 agitator machines, 3 cylinders, 1 agitating basket, and 1 modified agitator.

3. Water extraction methods had no significantly different effects on bursting and breaking strength, or on the shrinking and stretching of certain lingerie fabrics washed 50 times. Two wringers and 4 spinners were used for extraction. Types of washing mechanisms showed significantly different but inconsistent effects on all the factors studied. Washing mechanisms studied were 3 agitators, 1 agitating basket, 1 modified agitator, and 1 cylinder.

4. No correlation was found between the quantity of water used in the wash part of the cycle and the amount of soil removed. Tub capacities of the 19 washers studied ranged from 6½ to 20½ gallons. Among the 11 automatic washers, total water requirements were found to range from 26 to 60 gallons and hot water requirements from 13 to 39 gallons per load.

5. In general the 12 centrifugal extractors studied removed more water per load than the 6 wringers.

6. In an investigation of the effect of water extraction on soil removal by 6 centrifugal extractors and 6 wringers, results showed no significant difference between the two types.

Findings regarding certain factors in the washing process that influence the soil-removal ability of washers were:

1. Agitated soapy soaks of 5, 10, 15, and 20 minutes in 100° F. water with a 10-minute, 140° F. wash in an automatic machine increased the soil-removal index over that of a 10-minute wash without soaking. A soaking period of 15 minutes was more effective than 5 or 10 and also more effective than 20.

2. Within the limits of 120° to 160° F., the higher the temperature of wash water used, the greater was the amount of soil removal.

3. An increase in concentration of 3 detergents (2 syndets and 1 soap) from 0.2 to 0.3 to 0.4 percent in water of 300 p. p. m. hardness in 3 agitator machines having high, medium, and low soil-removal indexes, did not result in similar changes in soil-removal indexes. The soap increased the index with each increase in concentration in all washers, but the syndets were not consistent in their effects.

4. Beginning with a 5-minute wash period, 5-minute increases up to 20 minutes resulted in increases in soil-removal indexes of from 36 to 59 points. The greatest increase occurred between 5 and 10 minutes.

5. In experiments comparing the effects of a cold and warm rinse on white sheeting, no visible differences in whiteness were observed after 50 washings. There was a significant difference in favor of the warm rinse when analysis of reflectance readings was made.

6. Of 19 machines studied, all but 1 removed more soil with a 6-pound load than with the 8- to 10-pound loads given as the capacity of the machine by the manufacturer.

7. When washers were loaded with 10 pounds of bath towels, the increase in electric current used in 15 of 16 machines studied was not sufficient to indicate the possibility of injury to the motor.

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