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Performance Aspects of Water Conservation Techniques for Appliances

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

PREFACE

This report is one of a group documenting National Bureau of Standards (NBS) research and analysis efforts in developing water conservation test methods, models for technical and economic analysis, and strategies for implementation and acceptance of practices. This work is sponsored by the Department of Housing and Urban Development, Office of Policy Development and Research, Energy, Building Technology and Standards Division, under Interagency Agreement H-48-78.

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Abstract

The performance of household clothes washers and dishwashers is evaluated assuming various water conservation methods. For clothes washers the effect of fill level setting on soil removal is presented. A guideline for setting fill level is suggested. For dishwashers the soil removal capabilities are evaluated at reduced fill volumes. An analysis of the percentage of soil removed for each wash/rinse subcycle shows the relative quantities of soil in the discharge for each subcycle.

1. Introduction

A prior study [1]*of various water conservation techniques for appliances was conducted by the Center for Consumer Product Technology (CCPT) at the National Bureau of Standards (NBS). That study considered only the potential for reducing water consumption and did not address how the water reduction affected performance of the appliance. The performance of the appliance is closely related to the amount of water consumed in the operation. Although water savings can be achieved through various water conservation strategies, at some level the reductions in water consumption will be accompanied by a degradation in appliance performance. Decreases in appliance water usage beyond that point may result in greater overall water consumption due to consumer double-cycling of appliances, and can result in increased water usage.

The objective of the present investigation was to address the performance limitations of several specific water conservation techniques identified in the prior study. For clothes washers, the effect of fill level setting and load size on soil removal was addressed; based on that work, a method for adjusting fill level for optimum water savings was recommended. For dishwashers, the effects on performance of reduction in water volume on food removal from soiled dishware was investigated. In conducting the evaluation, the percentage of soil removed in each dishwasher wash/rinse subcycle was determined. The extent of degradation of the soil removed also served to give an indication of the relative effectiveness of each subcycle and to show that discharge water from selected cycles could be used in recycling systems.

2. Performance Aspects of Water Conservation in Clothes Washers

2.1 Clothes Washer Water Conservation

Results of the previous water conservation study [1] indicated that clothes washer water consumption may be reduced by several means, for example, use of front loading machines and use of suds-saver devices. In addition to these and other techniques which are built-in and therefore practicable only at the time of appliance purchase, more effective use of existing fill level controls by consumers was identified as a powerful water conservation technique. It was estimated, that through proper use of the level control, as much as 25 gallons per complete cycle might be saved in those cases where minimum fill could be used instead of maximum fill. More importantly though, if fill level could be set to match the real water requirement for each different load size, significant water savings should be realized by consumers. This would be especially important during water shortages.

Either by appropriate recommendations to consumers on fill level settings or by automatic level setting controls important savings could be realized; however, since water usage is closely tied to washer performance, such recommendations or controls must be based on consideration of performance at reduced fill levels. They must also be consistent with instructions provided to the consumer by the appliance manufacturer. The thrust of this current effort in the area of clothes washer performance was therefore to determine the

*Numbers in brackets indicate references in Section 10.

relationship between water usage and washing performance. This relationship provides the basis for fill level recommendations for water conservation—the final objective of the clothes washer portion of this study.

2.2 Clothes Washer Performance

Clothes washer performance is a multifaceted appliance characteristic. As such, overall performance cannot be given by any single factor. Many factors, including soil removal, rinsing effectiveness, and water removal, must be considered in a complete performance evaluation.

The most comprehensive set of criteria for evaluating clothes washer performance is a voluntary industry standard prepared by the Association of Home Appliance Manufacturers (AHAM) as AHAM Standard HLW-1, "Performance Evaluation Procedure for Household Washers," and subsequently adopted as a National Standard by the American National Standards Institute (ANSI) as ANSI 224.1-1971. This standard consists of seven separate test procedures, each covering a different aspect of clothes washer performance. These are:

- soil removal — removal of soil from fabrics
- sand removal — removal of insoluble and heavier-than-water soils from clothes and machine
- whiteness retention — retaining whiteness in unsoiled areas while removing soil from soiled areas
- rinsing effectiveness — rinsing laundering products from clothes
- water removal — extraction of water from wash board
- gentleness of action — effect of washing on fabric
- tangle free action — tangling of clothes among themselves and with parts of machine

Although developed by industry representatives, not all of the AHAM clothes washer test procedures are not currently in widespread use by manufacturers; in many cases various tests have been modified or have been replaced by more sophisticated tests to suit particular needs. Also, manufacturers have developed their own test procedures to evaluate additional performance factors, such as wear and abrasion. Nevertheless, the AHAM test procedures still fulfill their original purpose, that is, to obtain a measure of the performance of a given machine make and model under a given set of conditions.

Within the context of this study, evaluation of all performance factors as functions of water usage was not feasible. The time and equipment constraints, as well as the subjectivity of many of the test procedures precluded such an approach. Instead, activity was limited to evaluating the primary performance characteristic of the clothes washer, namely soil removal. Unlike many of the other performance tests, the soil removal test is objective in nature and can be carried out routinely.

2.3 Soil Removal Test

In the AHAM test, the soil removal characteristics of a clothes washer are determined through measurements of the optical reflectance of standard soiled fabric swatches made before and after washing. Materials used in the test procedure include standard soiled fabric, standard test loads, and standard detergent. Test conditions and data reduction formulas are specified in the standard (HLW-1). Unfortunately, the AHAM standard does not indicate how the Soil Removal Index (SRI), determined in the test, translates to performance, that is, excellent, good, or poor performance are not defined in terms of the SRI. Hence, the AHAM Soil Removal test must be regarded as a surrogate measure of performance, particularly for changes in performance.

2.3.1 Soiled Fabric

The standard soiled fabric is a white cotton cloth that has been treated with an artificial soil to simulate body oils and other soils; the resulting fabric is dark grey in color. The soiled fabric used in this study was obtained commercially from an AHAM supplier in the form of a nominal 18 inch roll. The fabric was certified to have a reflectance of 84.6 percent prior to soiling and 24.6 percent after soiling, as measured by a Hunter Reflectometer.

In accordance with the AHAM test procedure, the soiled fabric was cut into swatches measuring approximately 14 by 11 cm (5.5 by 4.3 in.). The swatches were numbered and then randomized to reduce any effects of non-uniformity throughout the bolt of fabric. The initial reflectance (before washing) of each swatch R_s was measured and the swatches were then pinned to the test load. A separate group of 20 swatches was used to normalize the soiled fabric by washing them in a Terg-O-Tometer*-- a standardized washing device specified by the test procedure.

2.3.2 Test Load

Two types of test loads may be used in the AHAM test procedures: the preferred AHAM Standard Mixed Cotton Test Load, consisting of various articles of clothing and household linens, or the AHAM Stuffer Load, consisting of 61 by 91 cm (24 by 36 in.) cotton cloth double hemmed on all edges. The latter test load was used in this study to facilitate testing.

2.3.3 Detergent

The detergent used in all tests was the AHAM Standard Low Sudsing Detergent No. 2A. A detergent concentration of 6.00 $\pm$ 0.40 grams per gallon of wash water was maintained at all fill levels.

2.3.4 Test Conditions

After affixing the soil swatches to the test load, the load was placed in the washing machine, detergent was added, and the wash cycle initiated. Wash (agitation) time used was 15 minutes or the maximum time provided by the

*"Terg-O-Tometer" is a standardized device manufactured solely by United States Testing Company, Inc. Its use is required by ANSI Z224.1-1971.

machine, whichever was shorter. For all tests, wash and rinse water temperatures were controlled at $60 \pm 1^{o}C$ ($140 \pm 2^{o}F$) and $38 \pm 3^{o}C$ ($100 \pm 5^{o}F$) respectively. Water hardness was maintained between 0-1 grains through use of a water softener.

2.3.5 Data Reduction

Upon completion of the cycle, the soil swatches were detached from the test load and air-dried. The final reflectance value, R_W, was then measured. The initial and final reflectances were converted to percent soil removed using the Kubelka-Mank equations. These are:

$$\left(\frac{K}{S}\right) = \frac{(1-R)^2}{2R} \qquad (1a)$$

and:

$$SR = \frac{\left(\frac{K}{S}\right)_s - \left(\frac{K}{S}\right)_w}{\left(\frac{K}{S}\right)_s \quad \left(\frac{K}{S}\right)_u} \times 100 \qquad (1b)$$

where:

K = coefficient of reflectivity
S = coefficient of light scatter
R = observed reflectance, soiled and
SR = percent soil removal.

The subscripts in Equation (1b) denote the condition of the test swatches, that is:

s = soiled fabric
w = washed fabric
u = unsoiled fabric

A value of 0.0089 is assumed for $\frac{K}{S}_u$. This value is based on numerous measurements made by AHAM and confirmed by the vendor of the soiled fabric.

In the test procedures, statistical measures such as standard deviation and variance of the soil removal values are calculated for both soil swatches washed in the machine under test and swatches washed in the Terg-O-Tometer. The soil removal values for the appliance are then normalized with respect to those for the Terg-O-Tometer to yield a Soil Removal Index (SRI). Normalization was not necessary in this study because all soiled fabric was from the same lot (bolt) and because changes in soil removal rather than absolute measurement of soil removal were of primary interest here.

3. Laboratory Testing

The soil removal characteristics of several different model clothes washers were evaluated at various fill levels. The objective of these tests was to investigate the relationship between fill level and performance; specifically, soil removal. Recommendations on fill level settings for water conserving operation were later made based on these test results.

3.1 Test Units

Five different clothes washers were selected for testing, three 1973-1974 and two 1978 models. All machines were large capacity, fully-automatic, top-loading units equipped with adjustable fill level controls. These machines represented a variety of different agitator/tub designs, but all machines except one operated in a similar mode, that is, wash, drain and spin with a spray rinse or rinses, deep rinse, and a final drain and spin. The one exception operated in the same mode but had an additional spray rinse during the final spin. Some characteristics of the test machines are presented in Table 1.

3.2 Tests Conducted

The soil removal characteristics of all five machines were evaluated using a 7 pound AHAM Stuffer Load and fill levels ranging from minimum to maximum. A 7 pound load was used because studies have shown that nearly one-third of all wash loads weigh between 6 and 8 pounds [2].

In a second group of tests, one of the five machines was tested at various fill levels using both 5 and 9 pound test loads. While it was recognized that these load sizes did not represent the extremes it was necessary to limit the range in order to ensure that the loads could be washed at both underfill and overfill conditions without having to modify the fill level control on the machine. It was felt that these fill levels would still provide an adequate basis for making fill level recommendations.

Upon determining the "optimum" water conserving fill levels, that is, the points at which a further reduction in fill level results in a perceptible degradation in performance, the relationship between fill height and clothes load height at these points was investigated. This relationship is discussed in Section 4.2.

4. Test Results

4.1 Soil Removal Tests

The results of all soil removal tests with the 7 pound load are presented in Figure 1. Each data point in Figure 1 represents the average of the average soil removal for the 15 standard soil swatches (tests at each fill level were repeated twice). It can be noted in Figure 1 that not all machines exhibit the same performance trends with differing water levels. For example, the performance of CW1 drops off continuously as water level is decreased, while the performance of CW2 and CW4 improves before dropping off (CW4 is the 1978 version of CW2 and is virtually identical in appearance). Also, the difference in soil removal from machine to machine is as large as the change in soil removal when water level is varied.

Because the AHAM test procedure does not relate soil removal values to washer performance, it does not provide a means of rating performance, that is, excellent, good, poor. Since the value of soil removal that represents acceptable performance is not defined under reference standards, it can only be stated that unacceptable performance occurs somewhere below the curve for machine CW4 shown in Figure 1. In reality however, when fill level is reduced, perceptable degradation in performance occurs before the average soil removal value drops below this level. The performance problem manifests itself in the laboratory as an increase in the spread of soil removal values measured for the 15 soil swatches used in each test. That is, soil removal from some swatches is significantly greater than average at low fill levels, while soil removal from other swatches is far less. In the home, some items of clothing would still appear soiled after washing.

The mechanics of the soil removal problem at reduced fill levels can be summarized as follows: when the fill level is reduced, the movement or circulation of the test load and swatches within the washer tub is inhibited; as a result, some swatches stay in the area of the agitator vanes and are washed well, while other swatches remain in relatively stagnant areas of the tub and receive little washing. The soil swatches which receive little washing, typically two of the 15 swatches, in tests conducted in this study, exhibit very low soil removal and are the main cause of low values of average soil removal for the run.

A plot of soil removal variance for all tests with the 7 pound load is presented in Figure 2. Here the data points represent the average of the variances for each of three test runs. It can be noted from Figure 2 that the soil removal variance for all machines tested behaves the same as fill level is reduced. In fact, three of the five machines have nearly the same soil removal variance for wash water use above 16.5 gallons, and the variance for the machines increases significantly as water use is reduced below this point.

Soil removal results for CW1 are shown in Figure 3 for tests with the 5, 7, and 9 pound test loads. Machine CW1 was selected for these tests because it was equipped with a 19 position fill level control and had the widest range of water usage of all machines tested. As Figure 3 illustrates, the trend toward lower soil removal values with decreased water usage holds for all load sizes. As before however, percent soil removal by itself does not lend insight into the circulation problem which develops as fill level is reduced—but the soil removal variance does provide correlation.

Figure 3 shows the increase in soil removal variance for all three loads as fill level is reduced. This increase is attributed to a direct result of a decrease in load circulation in the wash tub as fill level is reduced. The points at which the variance begins to increase significantly can be interpreted as the optimum fill level for water conservation. This interpretation has been confirmed by several clothes washer manufacturers. It is important to realize however, that the optimum fill level for water conservation may not be the best fill level with regard to other performance measures, for example clothing wrinkling and fabric wear. These other aspects of performance would need to be dealt with separately and are beyond the scope of this report.

The optimum fill levels for the 7 and 9 pound loads for machine CW1 are well defined--16.5 and 21.0 gallons of wash water, respectively as shown in Figure 3. The increase in variance for the 5 pound load is not as distinct, but begins to become significant somewhere between 10.5 and 13.5 gallons. The optimum fill level for this load size is therefore estimated as 12.0 gallons, the mean.

Since only one machine, CW1, was evaluated with test loads other than the 7 pound load, some relationship between load size and optimum water usage was desired so that the results for the other machines could be extrapolated to different load sizes. Ratios of parameters believed to be related to the washing process were calculated for this purpose. These parameters included optimum water usage, WU; test load weight, W_{TL}; test load volume, V_{TL}; volume of free water in the inner wash tub, V_{WIT}; and total volume in the inner tub, V_{IT}. Values of these parameters and several groupings of the parameters are given in Table 2.

It can be seen from Table 2 that ratios of wash water usage to test load weight or volume are approximately constant at the optimum fill level for each load size and these ratios can be used to estimate optimum water usage, e.g., for CW1 the optimum fill level is that for which $WU/V_{TL} = 13$. Since the optimum fill level for three of the four remaining machines was also about 16.5 gallons for a 7 pound test load, the water to test load volume for these machines is also about 13 (the proportionality constant 0.18 gallons per pound of test load is used to determine the volume of water displaced by the test load). Hence, the optimum water usage for all machines is approximately the same--12.0, 16.5, and 21.0 gallons of wash water for the 5, 7, and 9 pound loads, respectively.

It is interesting to note that for a 12 pound test load, the optimum water usage criterion $WU/V_{TL} = 13$ would dictate a wash water volume of 28 gallons--a volume in excess of the tub capacity. Consequently, water usage for this load size will be less than optimum and some non-uniformity in soil removal would be observed. This prediction is not surprising since a firmly packed 12 pound test load would fill the tub to near full capacity, thus inhibiting free circulation.

4.2 Fill Height and Load Height Measurements in Tub

The relationship between the height of the test load in the wash tub and the height of the water at optimum fill was investigated to provide a basis for fill level recommendations for water conservation. As a first step, the height of the water in the tub was determined as a function of wash water usage. From these relationships fill height was calculated for each of the optimum fill levels. The heights of the 5, 7, and 9 pound test loads in the tub were then measured under different methods of loading and compared to the fill heights.

4.2.1 Fill Height

Basically, a clothes washer consists of two concentric tubs--the inner perforated tub which holds the clothing and the outer solid tub which holds the water. Water in the disc-shaped void between the bottoms of the two tubs, and in the annular void between the sides of the two tubs does not take an active part in the washing process but nevertheless adds to water consumption.

As one would expect from the cylindrical shape of the outer tub, fill height as measured from the floor of the inner tub is essentially linear and is given by:

$$\text{Fill Height} = m\ (\text{water usage}) + b$$

The slope, m, of the straight line is directly related to the diameter of the outer tub and may be interpreted as the change in water level per gallon of water added; the intercept, b, is a depth measurement that is proportional to the volume of water in the disc-shaped void between the bottoms of the two tubs. Values of m and b for the five machines tested are given in Table 3. It can be noted from these values that each inch in fill height is roughly equivalent to two gallons of water. Also, for a given amount of water the fill level in CW2 and CW4 will be higher than in the other machines due to a smaller outer tub diameter (larger m) and reduced clearance between the bottoms of the two tubs (larger b) or conversely, for a given fill height (depth), the volume of water is reduced. As a result, these machines have a lower per cycle water consumption.

Based on the water usage/fill height relationships, the fill heights at optimum water usage can be computed. Fill heights for the machines tested are presented in Table 4 for the case in which the tub is filled with the clothes load already in the tub (as recommended in laundering guides accompanying new machines) and the case in which the tub is filled and the load is added later. The change in water level due to adding the load is only about 1 inch.

4.2.2 Load Height

The height to which a dry load of clothes fills the clothes washer tub is, for practical purposes, the only means of gauging the fill level needed for washing. By necessity then, any recommendations for setting the fill level must relate in some way to load height in the tub. Unfortunately, load height can be highly variable. Fabric types, wash load makeup, machine tub/agitator design, and loading technique all affect the load height. A cursory analysis of clothes load height in the tub was therefore undertaken to provide a basis for relating optimum fill level to load height.

The approach taken here was to measure the heights of the 5, 7, and 9 pound test loads in the tubs of the test machines under different loading practices, and then compare these values to the optimum fill heights. For these measurements it was recognized that the AHAM test loads do not represent the wide variety of fabric types and wash load makeups encountered in actual use; however, it was believed that the stuffer test load would reasonably indicate the relationship between fill level and load size.

The heights of the test loads in each machine were measured for two packing techniques. First, the load was lightly placed in the tub uniformly about the agitator in accordance with the AHAM method of loading, the result being a loosely packed load. After taking the height measurement the load was then firmly pressed down, eliminating much of the space between clothes and a final height measurement was made. Measured load heights are presented in Table 4 for loosely and firmly packed loads. For the sample test load used, the difference in load height between the loosely and firmly packed test loads was 4 to 5 inches.

4.3 Fill Level Recommendations

Comparison of the optimum fill heights to the test load heights, Figure 4, indicates that for the 7 and 9 pound loads, the water-conserving fill height occurs about midway between the loosely packed and firmly packed test load heights. For the 5 pound load the optimum fill height is closer to the load height when the load is firmly packed. In all but one case the optimum fill height is somewhere between the loosely packed and firmly packed load. Hence, a general guideline in setting the fill level might be: load the machine, pack the clothes moderately, and fill the machine to the height of the clothes load. The fill height should be referenced to some fixed point, perhaps a mark or scale on the agitator or tub, since the clothes load often tends to float during the fill.

The instructions on setting fill level that are provided new clothes washer owners by manufacturers are in good agreement with the fill level guideline identified in this study. Manufacturers generally recommend two criteria for setting fill level: 1) use enough water so that clothes circulate and turn over freely in the tub, and 2) use a fill level proportional to the amount (height) of clothes in the tub; as a specific example the following guideline is provided for one machine with a three position fill level control:

Load Size Setting	Amount of Clothes in Washer
Small	Less than 1/2 full
Medium	Between 1/2 - 2/3 full
Large	Over 2/3 full

Whether the first criterion, based on circulation, provides a good fill level setting depends on how "free circulation" is interpreted. Discussions with several manufacturers indicate that the number of "turnovers" (an observable measure of circulation) with a given load varies from one model machine to another, and with the same machine varies with both load size and fill level setting. The number of turnovers is usually about 10 to 15 in a 10 minute washing period, but can be as high as 30 and as low as 2 with the machine still giving satisfactory performance. Obviously, then, the first criterion is by no means definitive. The second criterion agrees more closely with that noted in this study, that is, the fill level should be proportional to the fill height.

It should be pointed out here that manufacturers include additional recommendations pertaining to fill levels when washing permanent press and delicate fabrics. Typically the recommendations are for the use of higher fill level settings for these loads. These recommendations are based on consideration of wrinkling and pulling of seams.

5. Clothes Washer Summary

5.1 Water Conservation

The effect of fill level setting on the performance of five top-loading clothes washers was determined using standard test procedures. The soil removal capabilities of all machines were evaluated using a 7 pound AHAM Stuffer Load and fill levels ranging from minimum to maximum. One of the machines was then tested at various fill levels using both 5 and 9 pound test loads.

Results of the soil removal tests indicated that the variance of the soil removal from each of 15 soiled swatches used in the tests was a better indicator of performance degradation than the average of the soil removal. As fill level was reduced, the point at which soil removal variance increased significantly was well defined. The fill level at this point was considered to be the "optimum" water conserving level, since any further reduction in fill would result in a greater non-uniformity in washing. Optimum fill levels were identified as those providing a wash water usage of 12.0, 16.5, and 21.0 gallons for the 5, 7, and 9 pound test loads.

It was noted that one inch of water in the washer tub corresponds to approximately 2 gallons of water. The ability to adjust fill level to within an inch or so is therefore highly desirable for water conservation purposes. Machines which provide for "finer" fill level adjustments should be promoted over those having only course adjustments.

The relationship between the height of the test load in the wash tub and the height of the water at optimum fill was then investigated. It was found that the optimum fill height occurs somewhere between the load height when the load is loosely packed and the load height when it is firmly packed. The fill setting guideline suggested from this work is: load the machine, pack the clothes moderately, and fill the machine to the height of the clothes load using a fixed point on the agitator or tub as a reference point. This fill recommendation is in agreement with instructions provided to consumers by clothes washer manufacturers.

5.2 Discharge Water

Total water consumption for a typical large capacity top-loading clothes washer is about 50 gallons for a normal cycle at maximum fill level—23 gallons each for the wash and deep rinse subcycles, and 3 gallons for the spray rinse. Clothes washer discharge water therefore represents a significant source of water for recycling systems. Reuse systems have been considered in detail by Bailey et al. [3] and have been demonstrated in several field installations [4, 5]. Therefore, the reuse of clothes washer discharge water has not been considered in this study.

6. Performance Aspects of Water Conservation in Dishwashers

6.1 Typical Dishwashers

A full line of dishwashers with varieties of control options are currently on the market; these range from the "basic model" to the "top of the line". Most dishwashers are equipped with several wash cycles and special features, depending on the particular model. Typical wash cycles include super or heavy-soil wash, pots and pans, normal wash, short or light wash, rinse and hold, and others. The consumption of water for the various cycles ranges from 2 to 4 gallons for the rinse and hold cycle to over 16 gallons for a heavy-soil cycle.

The typical "normal cycle" sequence consists of a wash, a rinse, a wash, and two or three rinses with a water change occurring between each of these subcycles. The phasing and number of these wash and rinse subcycles is not uniform among dishwashers even on the "normal cycle". Also, the amount of water used in a particular machine may not be uniform for each wash or rinse subcycle. Cycle phasing and water consumption information for several dishwashers, Table 5, illustrates this variation among models.

6.2 Dishwasher Water Conservation

As identified in the prior CCPT water conservation study [1], water savings of about 2 to 5 gallons are possible by using the short cycle when the dishes are lightly soiled. Such a cycle is equivalent to the "normal" cycle with one or two washes or rinses eliminated. Another technique identified, although not easily implemented by consumers, was reduction of the volume of water used per dishwasher fill or subcycle. With either of these two water conservation strategies however, adequate washing performance is necessary in order for any savings to be realized. Prior to making recommendations to consumers and planners regarding these water conservation options—an eventual goal of the HUD program—a study of the performance aspects of these options was therefore deemed necessary. In view of a lack of quantitative performance data on which to evaluate the feasibility of the water conservation options, such a study was undertaken by CCPT. The objectives of the dishwasher study were three: 1) evaluate the soil removal characteristics of the dishwashers under design conditions, 2) determine the effect on performance of eliminating a final rinse, and 3) determine the effect of reducing the volume of water used per fill or subcycle.

6.3 Dishwasher Performance

Unlike clothes washers, the performance requirements for dishwashers are quite simple--to remove soil from dishware and dry the dishware without spotting. As such, from an aesthetic point of view, soil removal is the most important single aspect of dishwasher performance. Bacteriological considerations are also important but are beyond the scope of this study.

6.3.1 Dishwasher Performance Test

Most manufacturers/distributors currently use the Association of Home Appliance Manufacturers (AHAM) standard test procedure DW-1 [7] to determine the performance (washing index, WI) of their products. Some companies however, use a yet more rigid test procedure than the DW-1, in an attempt to assure a more satisfactory product for the consumer. For the determining effects on performance of dishwashers with water conservation techniques the soiling portion of the AHAM test was used.

The DW-1 procedure for determining the washing performance of a dishwasher consists of washing a standard set of dishware place settings that have been soiled with specified foods that are difficult to remove. The foods are prepared and applied in a prescribed manner according to a timed procedure. After application, the soiled dishware is allowed to air dry. Then the dishware is washed using a standard AHAM detergent and a wetting agent to reduce spotting. The evaluation of the washing performance (washing index) is based on visual inspection of the dishware by a team of four trained judges who rate the cleanliness on the basis of the number and size of spots of food soil remaining on the dishware. A formula is used to reduce the data from each judge to a washing index, WI, representing the percentage cleanliness of the wash dishes. The four judges' results are averaged to obtain the final WI value.

The main disadvantage with this procedure for rating dishwasher performance is that it is a subjective method based on the visual observations of four judges. Therefore, it can produce a significant spread in percentage cleanliness ratings among the judges. An additional drawback is simply the effort required to judge the washed dishware. In view of these drawbacks an alternate approach was taken for evaluating dishwasher soil removal characteristics.

6.3.2 An Alternate Approach for Evaluating Dishwasher Soil Removal Characteristics

One objective of the present study was to determine the relative percentage of soil removed in each subcycle and evaluate the effect on performance when a rinse is eliminated and/or the quantity of water for each fill is reduced. One means of obtaining such information for a given machine would be to conduct the AHAM performance test on the machine for a complete operation cycle and to then report the test for truncated cycles. In this way, the significance of each additional subcycle is represented by the observed degradation in performance. Due to manpower requirements and subjectiveness of the AHAM test however, a measurement of soil removal in each subcycle was used. A breakdown of soil removal was determined by using the standard AHAM method for applying soil to the test dishware, but instead of judging the dishware after washing, the discharge water from each subcycle was filtered, and the residue weighed. This gave a measure of the undissolved solids removed in each subcycle. The actual procedure used was as follows: For each subcycle, a one liter sample of discharge water was collected. To remove the soil particles each sample was then passed through a [laboratory type paper] filter that had been dried in an oven at 40°C, weighed, and maintained in a desiccator before use. The soiled filter was dried and then reweighed to determine the weight of the soil removed per liter of discharged water.

The filtration technique yields a relative measure of soil removal, that is, soil removal for one subcycle relative to another may be obtained. This data, presented in Figures 5-9, is useful for determining the number of gallons of water from the subcycles that could be a potential source for grey water systems. However, since the amount of soil applied to the dishes or still remaining on the dishwasher cabinet or racks is not known, there is no simple way to determine the amount of soil still remaining on the dishware. As a result, this technique does not lead itself to the quantitative assessment of dishwasher performance.

7. Laboratory Testing of Dishwashers

7.1 Test Units

A total of 4 dishwashers from different manufacturers were tested using the "normal cycle" in each case. Some characteristics of these units are presented in Table 5. Test instrumentation and procedure were according to the Federal Register "Uniform Test Method for Measuring the Energy Consumption of Dishwashers" [6]. Energy consumption measurements were not conducted as part of this study, but are reported in References [9-10].

7.2 Tests and Results

7.2.1 Soil Removal Breakdown and the Effect of Eliminating a Rinse

An analysis of the water discharged by dishwashers was conducted to determine (1) the percentage volume of the food from soiled dishware that is removed by each water change, and how these percentages are distributed in a "normal cycle" for several typical dishwashers, and (2) what portion of the discharge water can be considered for use in a grey water recycling system. (The water discharged by a dishwasher into the household sewer system is referred to as "grey" water.) Analyses of the biological, chemical, corrosive, odor, storage, and distribution problems related to the applications of grey water recycling system are regarded as separate tasks and ones which may need to be performed in the future.

The soil removal for each of the four test dishwashers was determined using the procedure described in Section 6.3.2. The "normal cycle" was used in all tests. Four tests were conducted according to the procedure on Unit A. On the dishwashers Units B thru D, three tests each were conducted. The results for each machine were then averaged. The average percentage soil removed for each wash or rinse is plotted in bar graph format in Figure 5 for each dishwasher.

Examination of the bar graph data in Figure 5 indicates that the majority of all soil removed is removed in the first subcycle; also, the soil removed by the last two rinses of Unit C and last three rinses of Units A, B, and D is marginal—approximately 5 to 6% for Unit B, and 2 to 3% for Units A, C and D. A wash and two rinses constitute the last three water use functions designed in Unit C, while the last three water changes in Units A, B, and D perform only rinse functions.

It can also be noted from the bar graphs that soil removal during the final rinse is marginal. It would thus appear that the last one or possibly two rinses might be eliminated without sacrificing significant performance. Yet, while 1 or 2 percent soil removal does not amount to a large volume of soil, it can reduce performance and user acceptance if left on dishware in the form of specks and spots of food stuffs. For example, in tests previously conducted by NBS using the complete AHAM test procedure, the last rinse of Unit D was eliminated. Although the volume of soil normally removed in this rinse is minimal, the washing index of the machine, as determined by a panel of judges, was found to be 5 percentage points less than for the full cycle.

Analysis of the data in Figure 5 for the limited testing of these four dishwashers indicates that the water from the last three water changes could be considered a potential source for a stored "grey" water sweep system.

7.2.2 Effect of Reducing Fill Volume

A series of tests were conducted to determine if the household dishwasher can be operated on a reduced amount of water per fill without degradation of washing performance. The premise is that more water is used per fill than is required and a reduction of this is a potential source of water saving.

Each of four dishwashers was loaded with twelve soiled place settings of AHAM specified dishes except for a serving platter and serving fork. The time for each fill for each dishwasher was determined and then washing performance tests were conducted with the fill time reduced first by 25% (3/4 volume per fill) and then by 50%. Tests of 5% and 10% less water per fill were not conducted since this is in the range of variation due to the solenoid-operated fill valves. An external switch was used to interrupt power to the fill solenoid to obtain either 3/4 (25% water reduction) or 1/2 volume of water per fill (50% water reduction) depending upon which test was being conducted. Reductions in fill volume are directly proportional to reductions in fill time since the dishwashers fill at a constant rate [1]. No other electrical or time changes were made in the "normal cycle" as controlled by the timer.

Bar graphs for each of the four machines for full, 3/4 and 1/2 water volume for each fill are presented as Figures 6 through 9. Even though there was no absolute measure of the soil applied to the dishes or removed during the cycle, examination of the graphs indicates that less soil was removed in the early wash and rinse subcycles when washing with reduced fill. As a result, with reduced fill, a larger percentage of the soil was removed in the later subcycles. In some cases, such as with Unit D at 1/2 fill (Figure 9), substantial amount of soil were still being removed in the last rinses.

A visual inspection of the inside of the dishwasher and all dishes and flatware was made after washing a dishwasher load with reduced water volume per fill to determine the degree of performance degradation and whether rewashing was necessary. The criterion for determining whether a piece was to be rewashed was the subjective judgment as to whether or not a user would place the piece with the clean dishware supply. Test results are presented in Table 6.

The data in Table 6 shows that for a volume per fill of 3/4 for a single test on each of four dishwashers, 25 to 73% of the washed pieces needed rewashing and with only a 1/2 volume per fill, the percentage of rewashing required was 43 to 85%. Typically the unsatisfactory performance was due to undissolved detergent on the dishware, soiling food not removed from the original soiled dish or flatware, and food being removed from one piece and deposited on another piece not soiled with that material. In addition the inside of all four of the test dishwashers contained the soiling food and undissolved detergent on the dish racks and tub walls after both a 3/4 fill and a 1/2 fill cycle. This required a clean-up cycle to be run after each test before further testing could be conducted.

The largest number of pieces to be rewashed had been located in the upper racks of all dishwashers. This is due to the dishwasher pump not supplying water in sufficient quantity and at the required pressure to the upper sprayer, spray arm, or tower for the upper rack — a result of lack of water at the pump inlet. Both the lower and upper water rotating spray arms, towers, etc., depend upon water pressure from the pump to function properly.

The effect of reducing fill on the operation of the water distribution system was visually observed by replacing the door on one of these test dishwashers with a clear plastic door. With the normal volume of water per fill, the lower spray arm rotated at approximatley 52 revolutions per minute, but when the fill was only 1/2, the spray arm rotation dropped to approximately 31 revolutions per minute. In addition, with low fill the streams were weak from the lower spray arm from the upper distribution system functioned erratically or at times failed completely.

As a result of these tests, it is concluded that reducing fill volume is not a satisfactory method for obtaining a water savings in a dishwasher without engineering modifications to the water pump and spray system. Such modifications are discussed in Reference [1].

8. Dishwasher Summary

8.1 Water Conservation

The performance (washing index) of all dishwashers, as currently designed, would likely degrade upon elimination of a rinse in the "normal wash" cycle. Whether performance would be acceptable would depend upon the machine design and degree of soiling. Some machines can afford the slight reduction in performance which accompanies the rinse elimination, others simply cannot. The users must determine themselves, from trial and error, which loads can be washed with a short cycle. Consumer use of these cycles can result in water savings of about 2 to 5 gallons of water per cycle out of an average use of 14 to 15 gallons in the "normal cycle".

Limited testing on dishwashers, using 3/4 and 1/2 of the normal water per fill indicates degradation of washing performance, making this technique unacceptable for the user with currently designed machines. The dishwashers would have to be redesigned since with reduced water per fill the lower spray arm and upper water distribution systems malfunction and washing action is inhibited. Redesign would involve altering the geometry of the dishwasher sump region and the pumping and spray system to accommodate reduced water per fill. Recently, to save energy, some manufacturers have incorporated some of these features with the result that the amount of water used has been reduced by 1 to 2 gallons per cycle. As a result of these tests on earlier designed appliances it is concluded that reducing fill volume is not a satisfactory method for water savings in a dishwasher without engineering modifications to the water pump and spray system.

8.2 Discharge Water

Tests to determine the relative percentage of food particles removed during each water change by a dishwasher, either by a wash or rinse in the normal cycle, indicate that the soil content of the last three water discharges is low enough to permit the use of this water in a stored grey water recycling system. The grey water would be used to supplement the water required to remove solid wastes in a household sewer system and thereby conserve potable household water.

9. Conclusions

For determining the most water-efficient fill level for clothes washers, the variance of the soil removed from test swatches, rather than the average value of the soil removed, appears to be the best indicator for performance. Defining optimum water-conserving fill level as the level at which reductions in fill volume result in a marked increase in variance, a fill level guideline for consumers is suggested: load the machine, pack the clothes moderately, and fill the machine to the height of the clothes load using a fixed point on the agitator or tub as a reference point. For the clothes washers evaluated, each inch of water in the washer tub corresponds to approximately 2 gallons of water.

Use of the suggested fill method will permit satisfactory performance and also achieve water conservation.

Dishwasher performance degrades upon elimination of rinse subcycles, however, the large variability in both dishwasher design/performance and extent of dishware soiling, precludes blanket recommendations regarding the use of short cycle settings. Rather, consumers should be made aware of the water and energy savings associated with the various cycle settings, and be urged to experiment with them.

Additional research is still needed in several appliance-related areas, particularly:

- development of improved methods or schemes for rating appliances. Such methods would take into consideration water and energy consumption as well as performance in obtaining a measure of "overall" efficiency.

- analyses of tradeoffs between appliance water and energy usage, water temperature, washing time and other parameters, with the objective of reduced water and energy consumption without increased cost to consumers.

- biological studies of appliance discharge water, for application to grey water recycling/sweep systems.

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TABLE 1 - CHARACTERISTICS OF CLOTHES WASHERS TESTED

TEST UNIT	WATER LEVEL SETTINGS	INNER TUB DIAMETER-in	INNER TUB DEPTH-in	WATER CONSUMPTION[A] - GALLONS				MODEL YEAR
				MAXIMUM FILL		MINIMUM FILL		
				WASH CYCLE	TOTAL	WASH CYCLE	TOTAL	
CW1	19	20.5	15.8	23.7[B]	50.8[B]	6.2[C]	18.4[C]	1973-1974
CW2	4	20.8	15.5	18.7	41.3	9.8	23.6	1973-1974
CW3	4	21.5	15.8	25.1	53.7	11.9	27.4	1973-1974
CW4	4	20.8	15.5	19.6	43.4	8.5	20.8	1978
CW5	3	20.5	14.0	21.4	44.4	14.5	30.4	1978

A - With 7 pound load except as noted

B - With 5 pound load

C - With 9 pound load

TABLE 2 - PERFORMANCE RELATED PARAMETERS

TEST UNIT	LOAD SIZE (LB)	WATER USAGE AT OPTIMUM-WU (GAL)	TEST LOAD VOLUME-V_{TL} (GAL)	VOLUME OF WATER IN INNER TUB-V_{WIT} (GAL)	TOTAL VOLUME IN INNER TUB-V_{IT} (GAL)	$\frac{V_{WIT}}{V_{TL}}$	$\frac{V_{IT}}{V_{TL}}$	$\frac{WU}{V_{TL}}$
CW1	5	12.0	0.90	7.21	8.11	8.01	9.01	13.3
CW1	7	16.5	1.26	10.69	11.95	8.48	9.48	13.1
CW1	9	21.0	1.62	14.17	15.79	8.75	9.75	13.0
CW2,CW4	7	16.5	1.26	--	--	--	--	13.1
CW3	7	16.5	1.26	--	--	--	--	13.1
CW5	5	12.0	0.90	7.66	8.56	8.51	9.51	13.3
CW5	7	16.5	1.26	11.20	12.46	8.89	9.89	13.1
CW5	9	21.0	1.62	14.74	16.36	9.10	10.10	13.0

TABLE 3

WATER USAGE - FILL LEVEL RELATIONSHIPS

TEST UNIT	SLOPE* - M	INTERCEPT* - b
CW1	0.544	-0.873
CW2, CW4	0.616	-0.328
CW3	0.575	-0.687
CW5	0.553	-0.681

*Fill Level = M·(Water Usage) + b

Where
Fill level is inches
Water Usage is in gallons

TABLE 4 - FILL HEIGHTS AND TEST LOAD HEIGHTS

TEST UNIT	LOAD SIZE (LB)	WATER USAGE (GAL)	FILL HEIGHT W/CLOTHES (in)	FILL HEIGHT W/O CLOTHES (in)	TEST LOAD HEIGHT LOOSELY PACKED (in)	TEST LOAD HEIGHT FIRMLY PACKED (in)	FULLNESS WHEN FIRMLY PACKED (%)
CW1	5	12.0	6.14	5.66	9.93	6.16	39
	7	16.5	8.79	8.10	11.42	7.63	49
	9	21.0	11.43	10.55	13.70	8.95	57
CW2,CW4	5	12.0	7.62	7.06	10.61	5.61	38
	7	16.5	10.61	9.84	12.48	7.16	48
	9	21.0	13.61	12.61	13.88	8.00	54
CW3	5	12.0	6.73	6.21	11.10	6.05	38
	7	16.5	9.53	8.80	12.50	6.79	43
	9	21.0	12.32	11.39	14.03	8.15	52
CW5	5	12.0	6.45	5.96	9.29	6.12	45
	7	16.5	9.14	8.44	11.06	7.00	51
	9	21.0	11.83	10.93	12.83	8.94	65

TABLE 5

DISHWASHER CYCLE PHASING AND WATER CONSUMPTION

Test Unit	Water Consumption*, gallons Subcycle**							Total
DW1			R 2.6	W 3.1	R 3.1	R 3.1	R 3.3	15.2
DW2		W 2.4	R 2.0	W 2.0	R 2.1	R 2.1		10.6
DW3	R 2.1	W 2.2	R 2.7	W 2.2	R 2.2	R 2.3		13.7
DW6		W 2.2	R 2.2	W 2.2	R 2.2	R 2.2	R 2.2	13.2
DW7	W 2.7	R 1.8	R 1.8	W 2.7	R 2.7	R 1.8	R 2.7	16.2
DW8		W 2.4	R 2.7	W 2.7	R 2.7	R 2.7	R 1.5	14.7
DW10		W 2.4	R 2.4	R 2.4	W 2.4	R 2.4	R 2.4	14.4

*Supply pressure = 35 psig flowing
**W = Wash, R = Rinse

TABLE 6

PERCENTAGE OF DISHWARE REWASHED

Total pieces washed = 136 (dishes and flatware)

Dishwasher Unit	Volume per Fill	Total pieces rewashed	% rewashed
A	3/4	34	25
A	1/2	58	43
B	3/4	27	18
B	1/2	37	27
C	3/4	62	46
C	1/2	85	63
D	3/4	99	73
D	1/2	114	84

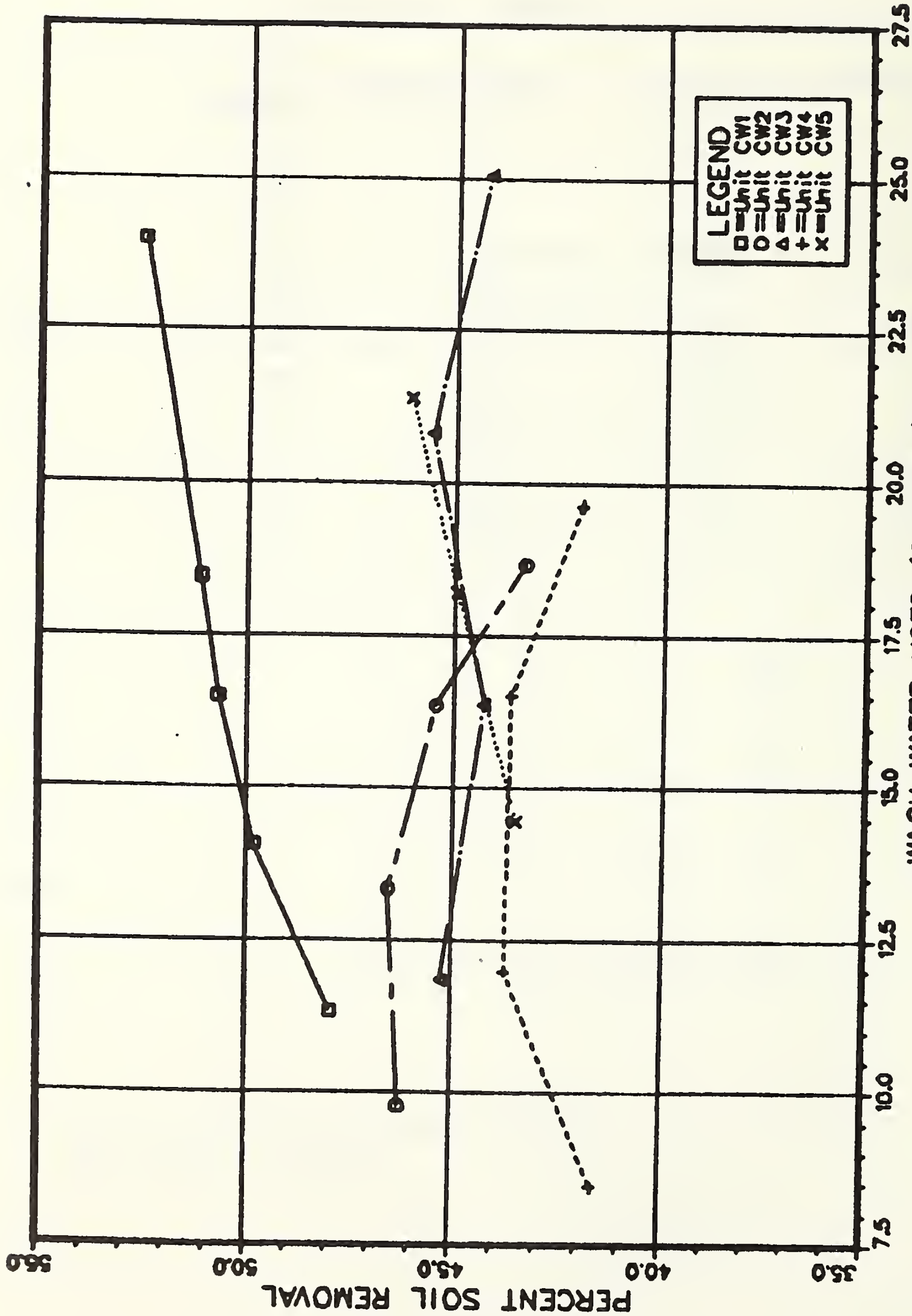

FIGURE 1. AVERAGE SOIL REMOVAL VERSUS FILL LEVEL -- 7 POUND LOAD

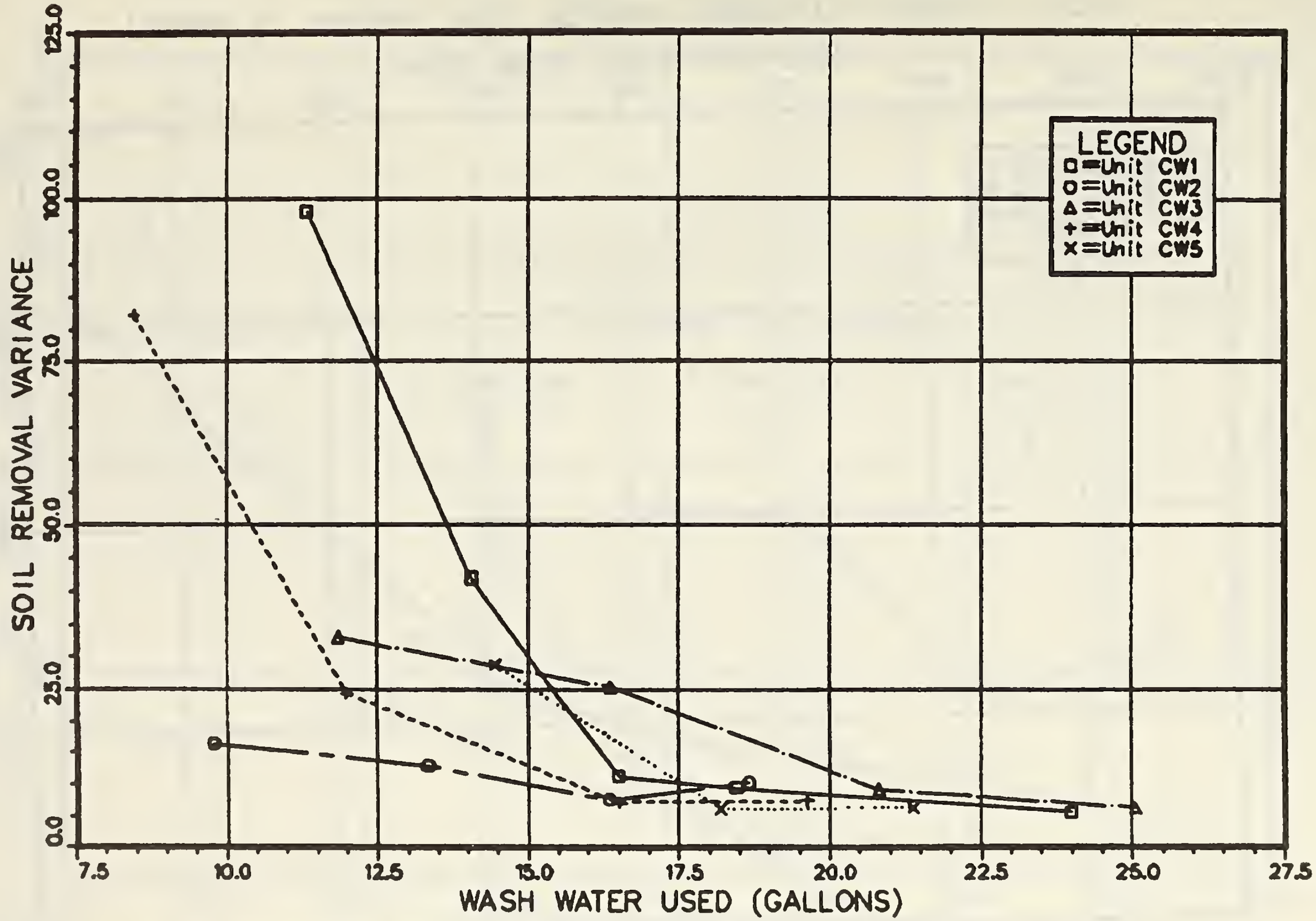

FIGURE 2. SOIL REMOVAL VARIANCE VERSUS FILL LEVEL -- 7 POUND LOAD

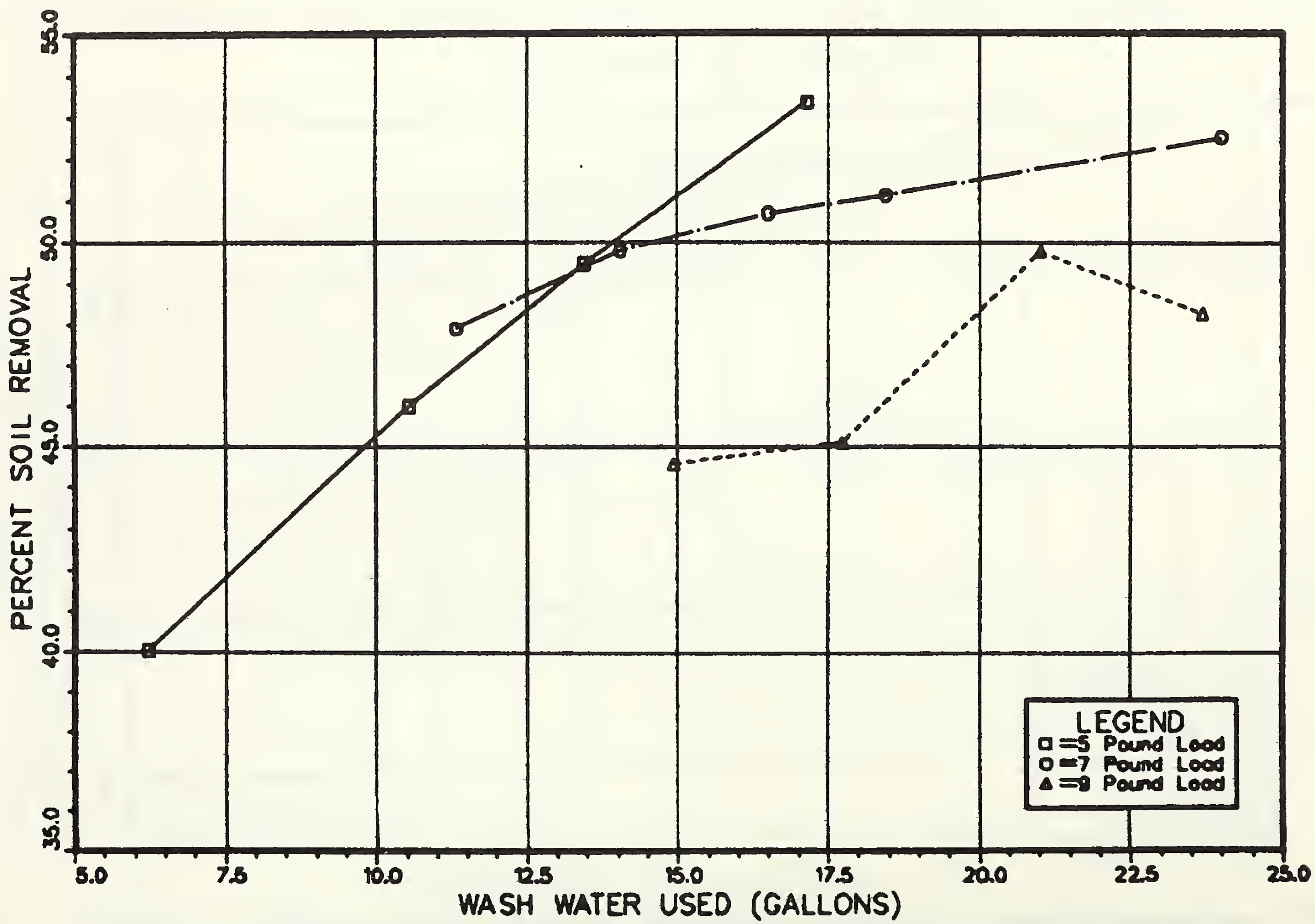

FIGURE 3. AVERAGE SOIL REMOVAL VERSUS FILL LEVEL -- CW1

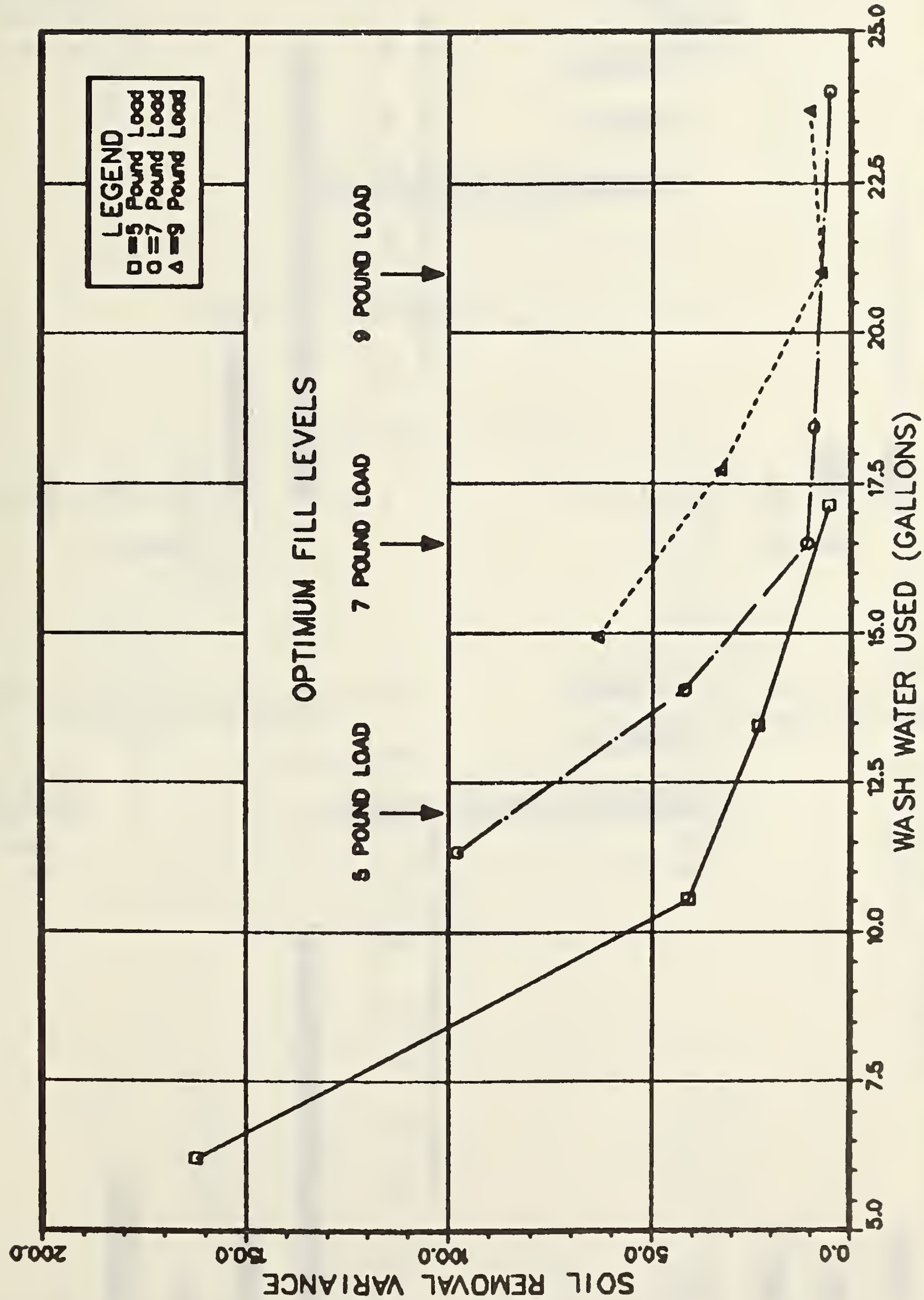

FIGURE 4. SOIL REMOVAL VARIANCE VERSUS FILL LEVEL -- CW1

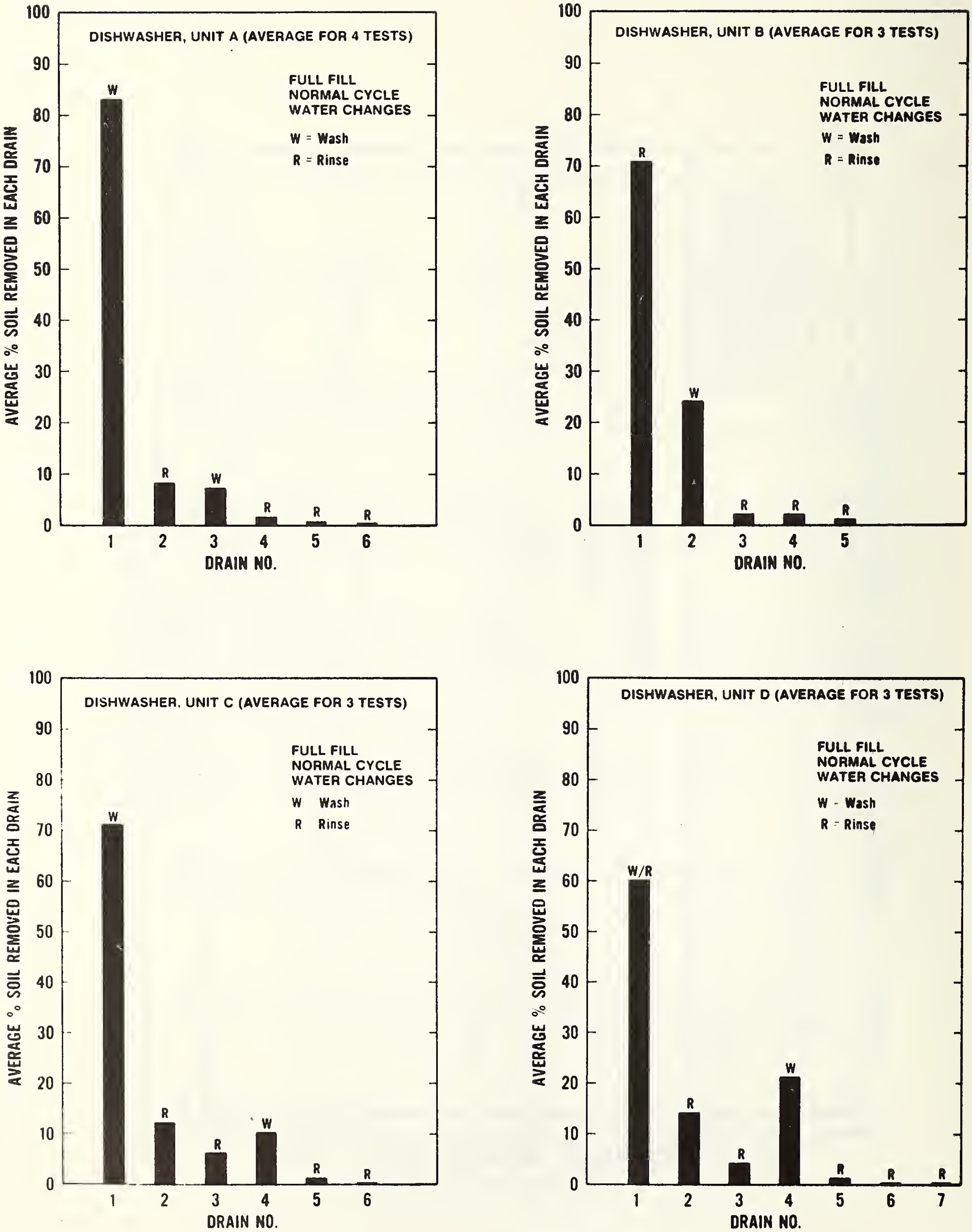

FIGURE 5: SOIL REMOVAL PER SUBCYLE--ALL UNITS AT FULL FILL

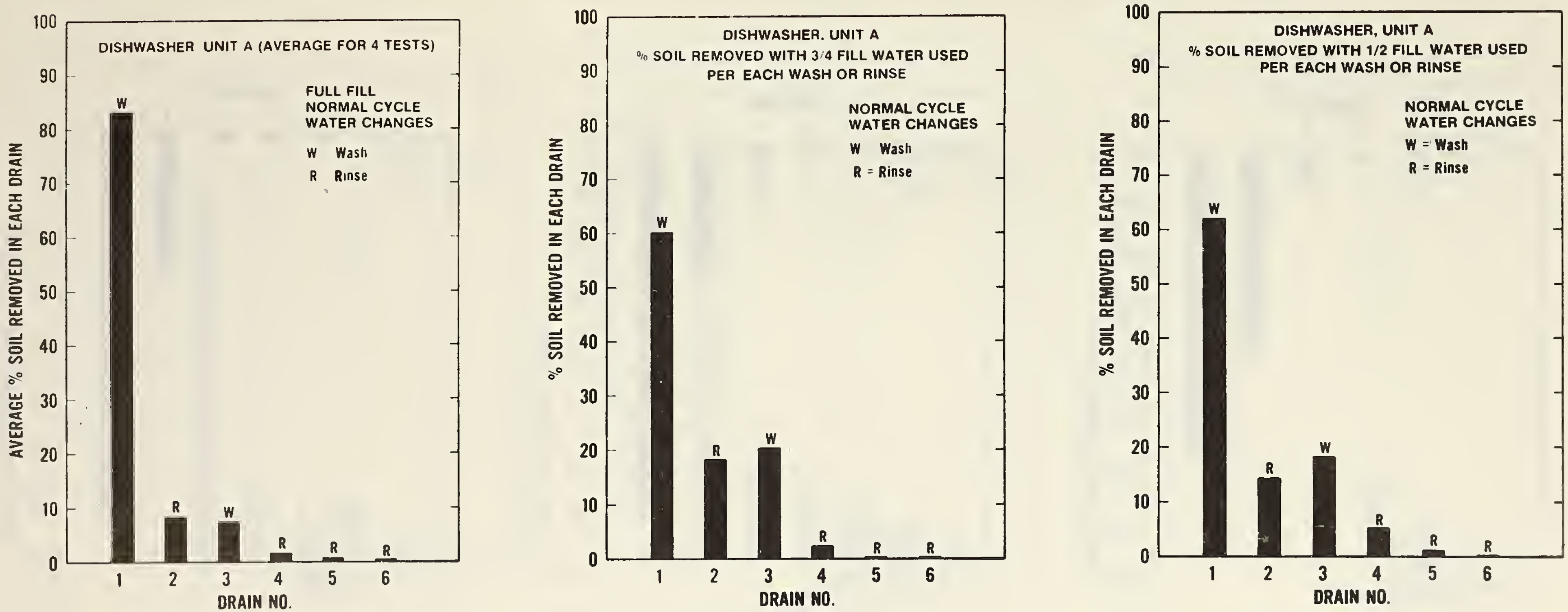

FIGURE 6: SOIL REMOVED PER SUBCYLE--UNIT A; FULL, 3/4, and 1/2 FILL

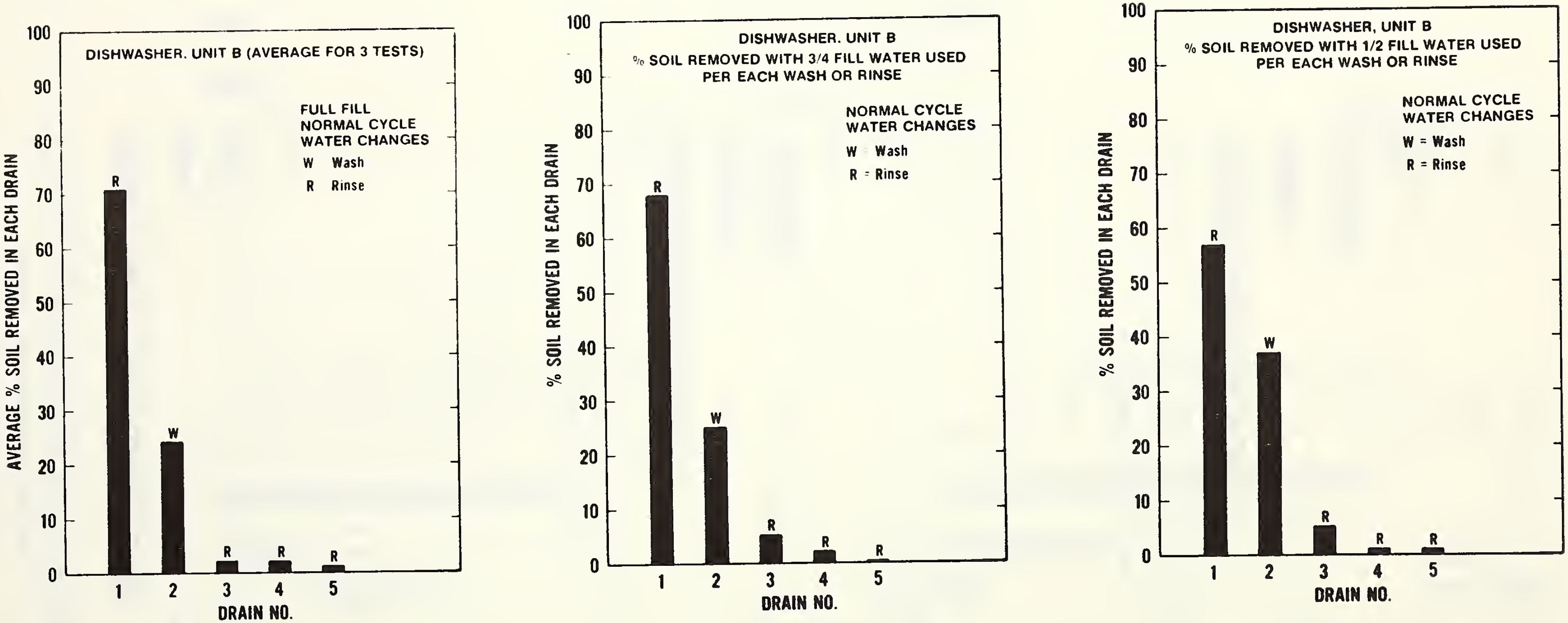

FIGURE 7: SOIL REMOVED PER SUBCYCLE--UNIT B; FULL, 3/4, AND 1/2 FILL

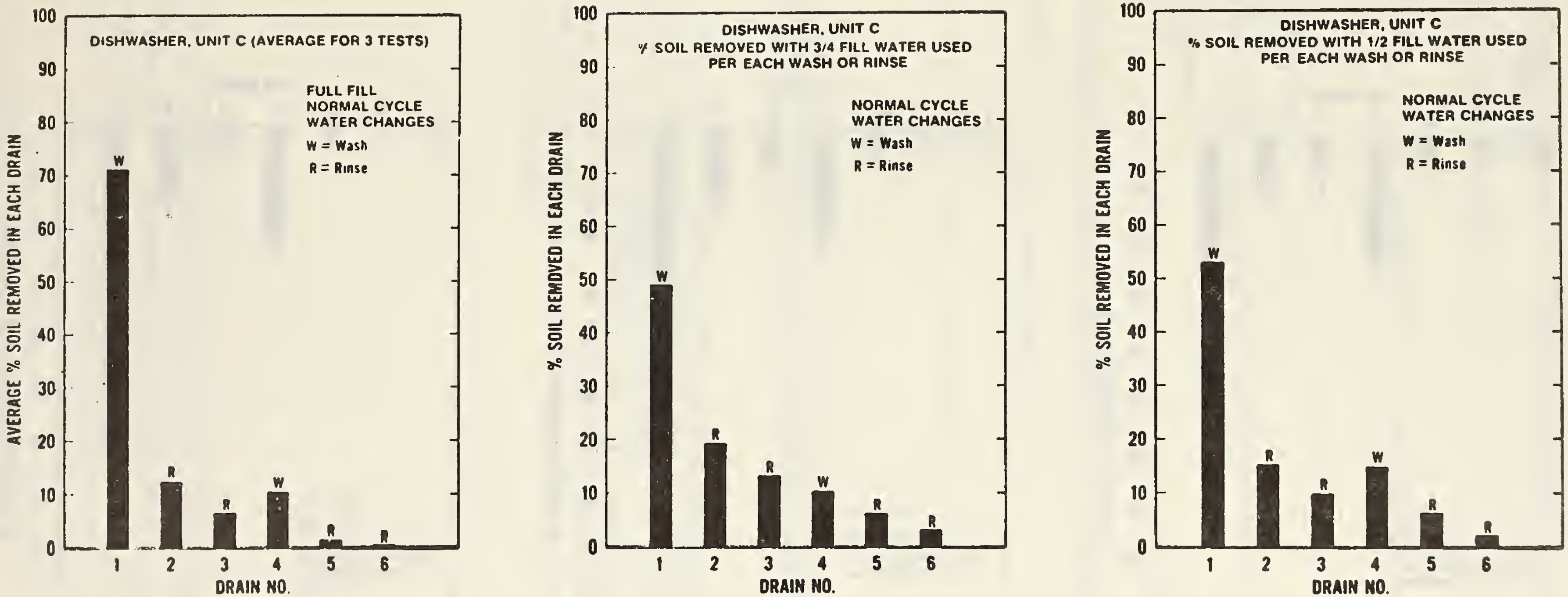

FIGURE 8: SOIL REMOVED PER SUBCYCLE--UNIT C; FULL, 3/4, AND 1/2 FILL

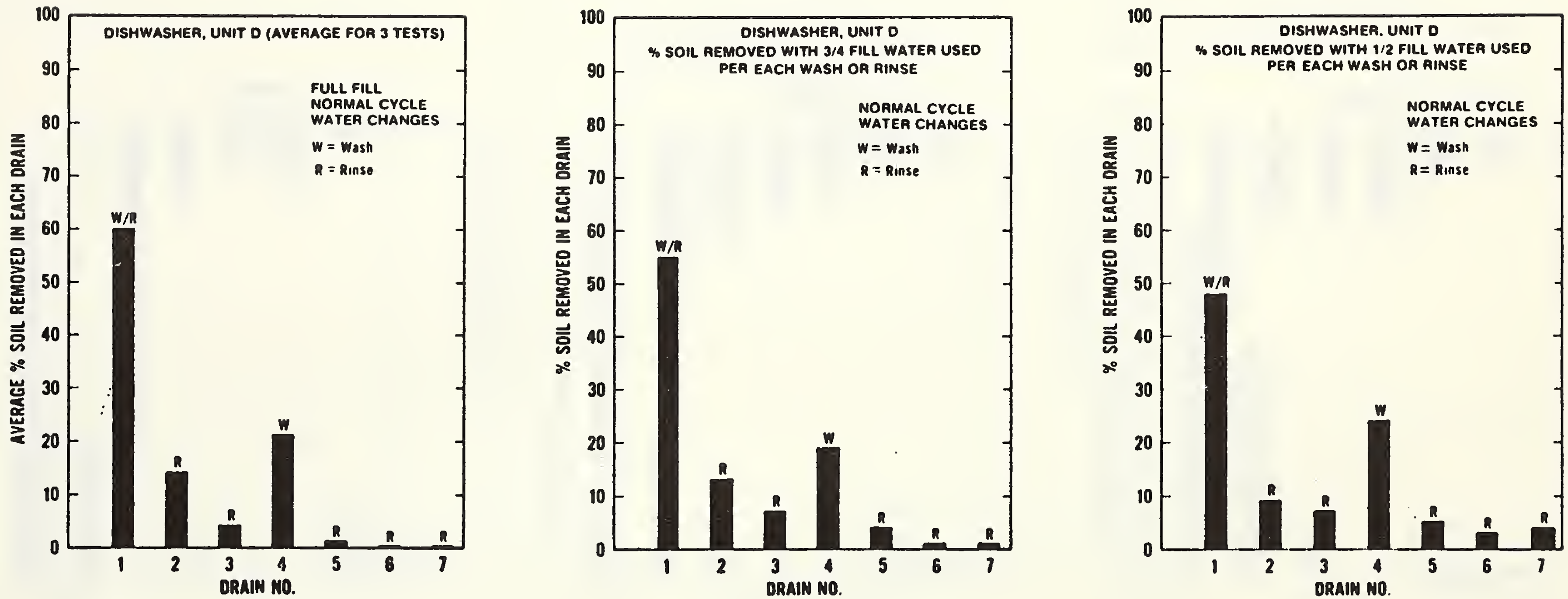

FIGURE 9: SOIL REMOVED PER SUBCYCLE--UNIT D: FULL, 3/4, AND 1/2 FILL

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The performance of household clothes washers and dishwashers is evaluated assuming various water conservation methods. For clothes washers the effect of fill level setting on soil removal is presented. A guideline for setting fill level is suggested. For dishwashers the soil removal capabilities are evaluated at reduced fill volumes. An analysis of the percentage of soil removed for each wash/rinse subcycle shows the relative quantities of soil in the discharge for each subcycle.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Clothes washers; dishwashers; dishwasher subcycles; fill controls; grey water; performance; soil removal; water conservation; water discharge characteristics

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