The New U.S. Department of Energy Dishwasher Test Procedure: Development and First Results

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The policy of the National Institute of Standards and Technology is to use the International System of Units (metric units) in all its publications. However, in North America in the construction and building materials industry, certain non-SI units are so widely used instead of SI units that it is more practical and less confusing to include measurement values for customary units only.

ABSTRACT

This paper summarizes the main changes to the Department of Energy's (DOE, Department) test procedure for residential dishwashers and the collaborative efforts with industry that led to those changes. The test procedure outlined here is a model for future DOE and industry efforts. The paper also presents comparative energy consumption results for two soil-sensing dishwashers tested with both the revised and the original test procedure. The test results, which showed a small increase in energy consumption when using the revised test procedure, were an important step in validating and demonstrating the DOE test procedure as a means to obtain energy efficiency factors that consumers can rely on for making purchase decisions.

BACKGROUND

Soil-sensing dishwashers measure operational values (e.g., turbidity, pressure, temperature) and adapt the wash cycle based on the information collected. Because of the dishwasher's responsiveness to different soil levels, the DOE test method for dishwashers, using clean dishes, was inaccurate for the purpose of rating energy consumption. The energy consumption results using clean dishes were believed to be significantly lower than the levels consumers would likely experience. Therefore, a way to reflect the soil level on consumers' dishware needed to be defined and translated into a reliable energy consumption test procedure. In addition, standby power consumed when the dishwasher was not performing a cleaning cycle was previously not factored into the energy consumption reported to consumers.

THE RULEMAKING PROCESS

When developing Federal appliance energy standards and the test procedures that support them, the U.S. Department of Energy must weigh what is technologically feasible against what is cost-effective, carefully considering both the interests of consumers and the financial impacts on manufacturers. The importance of expediting a new test procedure for soil-sensing dishwashers to improve the accuracy of energy labels united the interests of a range of stakeholders and produced an effective coalition of effort supported by manufacturers and consumer and environmental advocates.

The Department first worked with manufacturers and the National Institute of Standards and Technology (NIST) to develop a modified clean-dish test procedure for soil-sensing dishwashers that used a formula to weight and average the energy consumption of the minimum and maximum soil-sensing dishwashing cycles. These cycles would be artificially forced by manufacturers for test purposes, instead of being triggered by appropriate food levels. When the Department presented this alternative clean-dish test method in a Notice of Proposed Rulemaking published in the *Federal Register* [1], however, participants in the subsequent public hearing expressed a range of concerns, and it was agreed that more

research was needed to accommodate the variety of sensor technologies used in the evolving dishwasher market. In addition to understanding the performance and responses of the dishwashers themselves, additional statistical information was needed regarding the typical soil loads encountered by today's dishwashers. How much food were dishwasher users leaving on their dishes for dishwashers to clean?

Industry, environmental advocates, and consumer interest groups such as Consumers Union recognized the importance of understanding how soil-sensing dishwashers performed under "typical" soil conditions, and what those "typical" soil conditions actually were. DOE held not only structured public hearings, but additional working meetings with stakeholders to develop collaborative strategies to obtain the necessary data, building on the gradual consensus conclusion that only a test procedure using soiled dishes, not clean, could obtain accurate results.

As the Department learned that various research projects and surveys had already been conducted by manufacturers and other stakeholders, the next challenge was to find a way to evaluate the proprietary information, and to determine if that information was nationally significant and could be used to support a Federal appliance rulemaking. DOE hired an independent research organization, Arthur D. Little, whose technology and innovation business has become known as TIAX LLC, to work with industry stakeholders, to collect the confidential data and to evaluate all available surveys and studies regarding consumer dishwasher use. TIAX staff produced two reports, *"Review of Survey Data to Support Revisions to DOE's Dishwasher Test Procedure"* and its addendum [2, 3]. The Department posted these reports on its website to elicit additional stakeholder input, each time, refining the process and developing consensus. Finally, a new test method using soiled dishes had been developed and was ready for public presentation and consideration in a second Notice of Proposed Rulemaking [4].

The following section presents a summary of the survey review findings on consumers' dishwasher usage habits. The complete reports can be found on-line at: *http://www.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html.*

SURVEY REVIEW-Consumer Usage Data

To support revisions to the Department of Energy's test procedures for measures of energy consumption in dishwashers, TIAX worked with a number of sources to collect and review a variety of both public and proprietary survey data on consumers' dishwasher usage habits. The survey review was based on: 1) review of existing industry and DOE dishwasher test standards; 2) review and analysis of survey information from eight individual sources including dishwasher and detergent manufacturers, energy and consumer interest groups, independent researchers, and government agencies; and 3) discussions with key personnel in industry, DOE, NIST, consumer groups and TIAX.

The review showed broad support to define several key parameters:

1. Consumers' pretreatment habits,
2. Distribution of households by the level of soil on the dishware,
3. Quantitative amount of soil on the dishware, and
4. Frequency of households' use of a dishwasher.

The following sections briefly describe these key parameters.

Consumers' Pretreatment Habits

Survey data clearly indicated that more than 70 % of U.S. households pretreat dishes with water prior to placing them in the dishwasher. Figure 1 shows the aggregation of the surveys' responses to questions on pretreatment habits. The simple import of this finding is that currently the vast majority of U.S. households' dishwasher loads are cleaner than they would be without pretreatment.

Distribution of Households by the Level of Soil on the Dishware

Half of the surveys (4 out of 8) provided information on the level of soil on the dishware going into the dishwasher. These surveys distributed responses into categories describing soil level. TIAX's analysis simplified these categories and their descriptions to three levels—Light, Medium, and Heavy. All but one small regional survey showed similar trends. Aggregating the two nationally representative surveys and weighting the responses in each category by the total number of respondents yielded a distribution of households within the three soil level categories—Light,

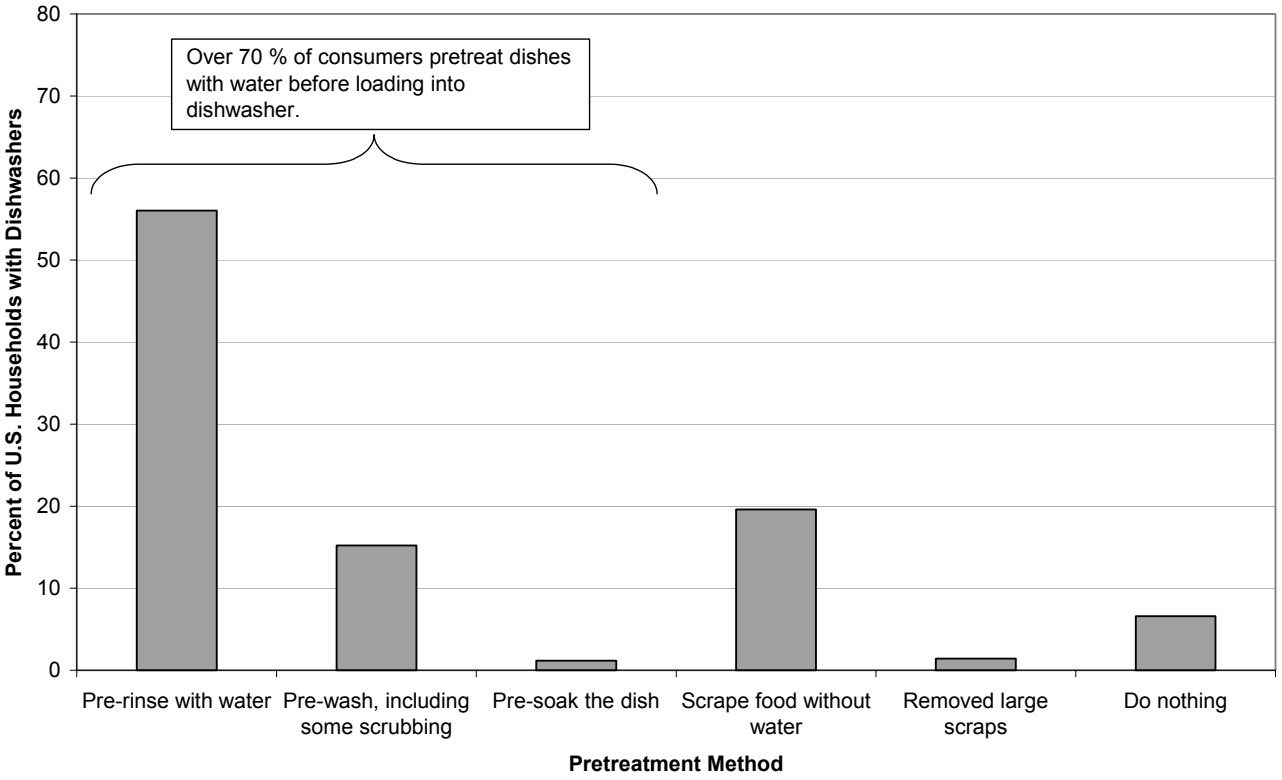

Figure 1: Distribution of U.S. Households by the Level of Soil in Dishwasher Loads

Medium, and Heavy—of 62 %, 33 %, and 5 %, respectively, as shown in Figure 2.

Quantitative Amount of Soil on the Dishware

The available surveys provided only limited information on the types of soil on the dishware of U.S. households. Similarly, broader industry experience revealed the difficulty of inventorying soil types on the dishware of U.S. households and representatively recreating those soils for the purpose of testing.

However, the Association of Home Appliance Manufacturers (AHAM) had spent considerable effort to define the industry-recognized, "worst case" cleaning performance test in the American National Standard (ANSI/)AHAM Standard DW-1-1992 [5]. DW-1 precisely defines: 1) food soils that are representative of the types of soils on the dishware of U.S. households; 2) amounts of those food soils, and 3) procedures to apply the food soils and to prepare the dishware for testing. DW-1 meets industry requirements for test repeatability.

Several surveys provided some level of information on the quantitative amounts of soil left on dishware. However, one proprietary survey provided nationally-representative, detailed data on the quantitative amounts of soil left on dishware. The authors of this survey categorized detailed data, largely in the form of thousands of systematic photographs of households' soiled dishwasher loads, into a ten-level Likert scale[1]. Working with the survey authors, TIAX recategorized the data into the three qualitative soil levels—Light, Medium, and Heavy. The photographic data

[1]Likert scale- A response scale, developed by Rensis Likert, used for assessing opinions and usually consisting of 5 or more categories. As a semi-variable approach it provides more information than the simple attribute (yes-no) question.

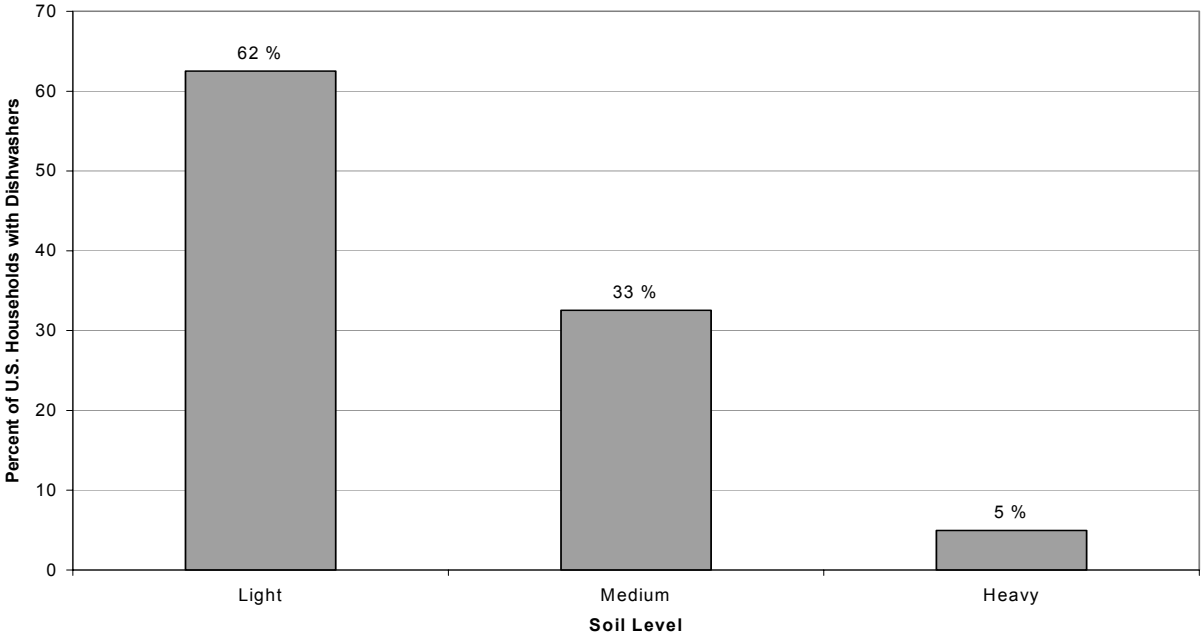

Figure 2: Distribution of U.S. Households by the Level of Soil in a Dishwasher Load

provided the key to determine the quantitative amounts of soil for each level. TIAX used ANSI/AHAM Standard DW-1 as a reference to define the types of soil and, most importantly, the amounts of soil in each of the three soil levels. The amounts of soil representative of each of the three soil levels was expressed in terms of the number of dishware place settings soiled per ANSI/AHAM Standard DW-1. The three soil levels were defined as follows: Light—one place setting with one half the amount of soil normally applied; Medium—two soiled place settings; and Heavy—four soiled place settings.

Frequency of Households' Use of a Dishwasher

In addition to data specifically supporting a test method for soil-sensing dishwashers, TIAX's review showed that consumers' usage of a dishwasher, soil-sensing or otherwise, was significantly less frequent than had been estimated in the dishwasher test procedure. A publicly available source, the Energy Information Administration's 1997 Residential Energy Consumption Survey [6], showed that more than half of U.S. households with a dishwasher use it less than 4 times per week. This clearly suggested that the number of representative average-use cycles per year for a dishwasher should be in the vicinity of 208 cycles per year.

Several other large, nationally-representative surveys offered data that also indicated that the frequency of dishwasher use was somewhere in the range of 200-233. An aggregation of the nationally-representative surveys' responses, shown in Figure 3, illustrates this trend. Based on the survey findings, the Department selected 215 as the average number of dishwasher use cycles per year.

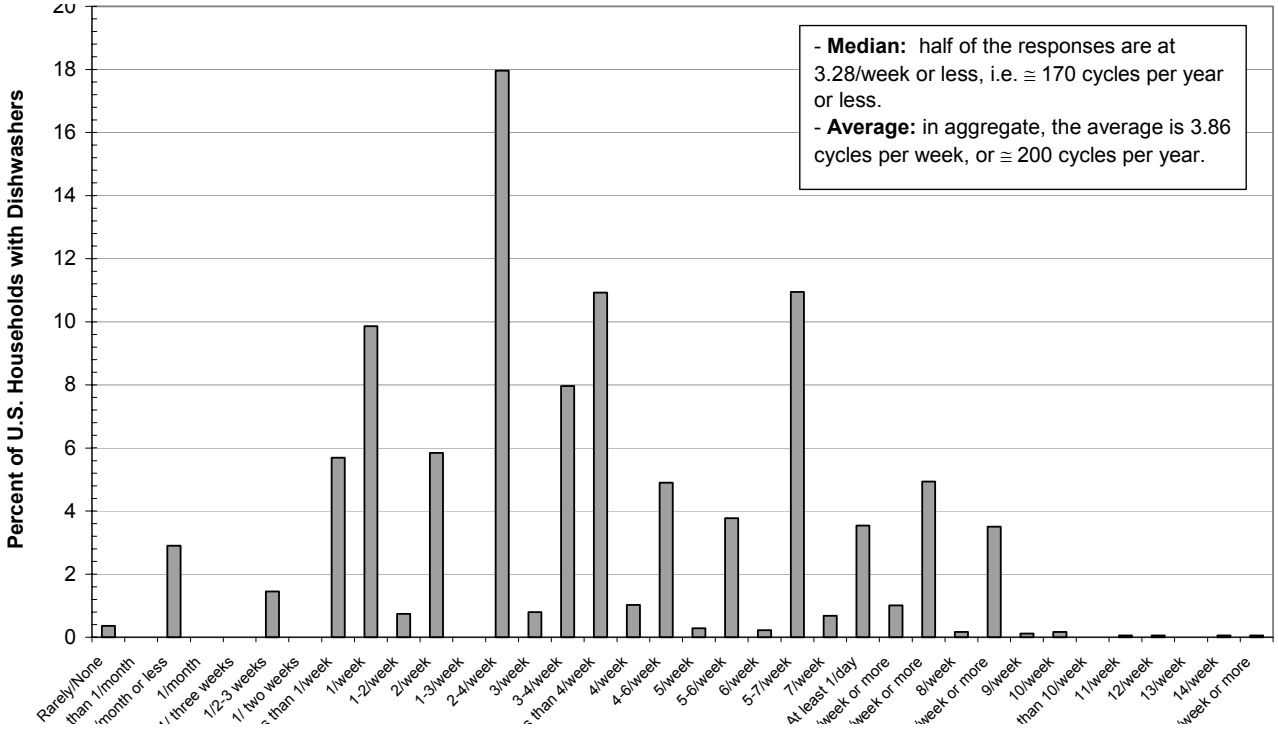

Figure 3: Aggregate Distribution of U.S. Households' Use of a Dishwasher

THE REVISED DOE TEST PROCEDURE

By combining standby energy consumption with the energy consumed during the wash cycle, calculations in this test procedure provide consumers with more realistic and accurate estimates of the complete operating cost and energy use of each dishwasher. It provides a better approximation of the actual energy consumption of soil-sensing models as consumers use them than did the original test which used clean dishes and did not engage the action of the soil-sensing mechanisms to take a dishwasher beyond the lightest wash cycles.

Manufacturers or private labelers must now determine if the dishwasher is soil-sensing or non-soil-sensing, depending on whether it has the ability to adjust any energy-consuming aspect of a wash cycle based on the soil load of the dishes, and then follow instructions specific to that type of model.

Under the revised test procedure, manufacturers must test soil-sensing dishwashers using the weighted, three-point test method.

At the public hearing stakeholders widely accepted this revised and final version of the weighted, three-point test method for soil-sensing dishwashers. The Department of Energy published the revised test procedure for residential dishwashers on August 29, 2003 [7] to enable better testing of soil-sensing models and the measurement of standby power for all models. Although the revised test procedure would potentially increase the energy consumption values for some models, the Department retained the same minimum energy standard, (an energy factor (EF) of at least 0.46 cycles per kilowatt hour for standard-size dishwashers and 0.62 cycles per kilowatt hour for compact models) because industry stated that there were no marginally compliant models that would fail to comply using the new test procedure. The energy factor is the basis of comparison for all models.

Soil Load

By introducing a soil load, soil-sensing dishwashers have a test procedure that challenges the cycle responses that the sensing technology controls. The revised test procedure references the ANSI/AHAM DW-1 [5] standard for specifications on the size and composition of the place settings and the quantities and types of soils which must be applied to the dishes for the series of three soil tests: heavy, medium and light. The testing sequence of 1) heavy, 2) medium, and 3) light was selected to obtain a more realistic energy response because some control algorithms use the previous wash cycle as an input to determining the wash intensity for the next cycle.

After running a preconditioning cycle, a standard-sized dishwasher's heavy response is tested, using four soiled place settings and four clean place settings; second, the medium response is tested, using two soiled place settings and six clean place settings; and third, the light response is tested, using one-half the soil load for a single place setting and seven clean place settings. Tests of compact models are the same except that for the heavy and medium tests soil loads are reduced by half. For each of these tests only half the detergent in the ANSI/AHAM DW-1 performance test is used and rinse agent is omitted.

The Energy Factor Calculation

Drawing from the survey review findings, the original test procedure for dishwashers, and ANSI/AHAM Standard DW-1, DOE, TIAX, and NIST put forth a weighted, three-point test method using different numbers of soiled dishware for energy and water consumption measurements of soil-sensing dishwashers. Stakeholders submitted comments on the weighting factors and as a result, DOE and TIAX refined it with additional detailed consumers' dishwasher usage data.[3]

The energy consumption for each of the three tests is measured and calculated in the same way as the original test method. However, the energy factor for a soil-sensing dishwasher is now based on a weighted average of the three energy consumption tests. The weighting factors are the percentages for the distribution of U.S. households in the three soil level categories – 62 % Light level of soil, 33 % Medium, and 5 % Heavy (see Figure 2).

Incorporating the weighting factors with the energy consumed in each test yields an energy factor for soil-sensing dishwashers as defined in Equation 1.

Equation 1 – Energy Factor (EF) for Soil-Sensing Dishwashers

$$EF_{soil\text{-}sensing} = 1/\ [(.62 \times \text{Test\#1Energy}) + (.33 \times \text{Test \#2 Energy}) + (.05 \times \text{Test \#3 Energy})]$$

Standby Power

Many soil-sensing dishwashers and selected non-soil-sensing dishwashers consume standby power, a constant low level of power to retain information necessary for their operation. With the revised DOE test procedure, standby mode is defined, along with the required measurement equipment and method for calculating standby energy consumption.

Two options are available for measuring standby energy consumption, depending on whether the stability criteria are met. power usage is stable. If 1) the standby power consumption is stable and 2) the variation in the power levels is less than 5 % of max, manufacturers or private labelers can measure the instantaneous power level using a wattmeter. However, if the stability criteria are not met, Manufacturers or private labelers must measure the energy consumption using a watt-hour meter over a period of at least 5 min and calculate the average standby power by dividing the energy measured using the watt-hour meter by measurement time. The estimated annual standby power use, S, is expressed in kilowatt-hours per year and defined in Equation 2.

Equation 2 – Estimated Annual Standby Power Use, S

$$S = S_m \times ((H_s)/1000)$$

where,

S_m = average standby power measured in watts

H_s = number of standby hours per year (calculated in the test procedure)

These changes provide the means to obtain a quantitative value for the level of standby energy that the dishwasher consumes. Manufacturers or private labelers must add this standby energy amount to the machine energy and water energy computed for the normal cycle and representative normal cycle for soil-sensing models. This

combined energy consumption is used to determine the Estimated Annual Operating Cost (EAOC) and the Estimated Annual Energy Use (EAEU).

Non Soil-Sensing Dishwashers

For non soil-sensing dishwashers, manufacturers or private labelers will still use clean dishes to determine the energy factor as the average of the test results from the normal and truncated normal cycles. In addition, manufacturers or private labelers must calculate the standby power consumption for any dishwasher using energy in standby mode and add that figure to the EAOC and EAEU totals, but not to the energy factor.

Only dishwashers that are both non-soil-sensing and non water-heating are tested without a test load.

The next section describes the verification studies that were conducted as part of the test procedure development process, before publishing the final rule. These tests were carried out to determine whether the test procedure could effectively measure the energy and water consumption of models using different soil-sensing technologies.

VERIFICATION TESTING AND ANALYSIS

NIST tested two types of soil-sensing dishwashers using the revised test procedure. An automated data collection program was designed to record data as well as to display the operating functions in real time. In the models tested, soil levels are sensed either with an optical turbidity sensor or a pressure sensor at the food filter. Sensor readings are inputs to the dishwashers' wash algorithm to determine the appropriate wash intensity for the cycle.

The graphical user interface shown in Figure 4 enables the test

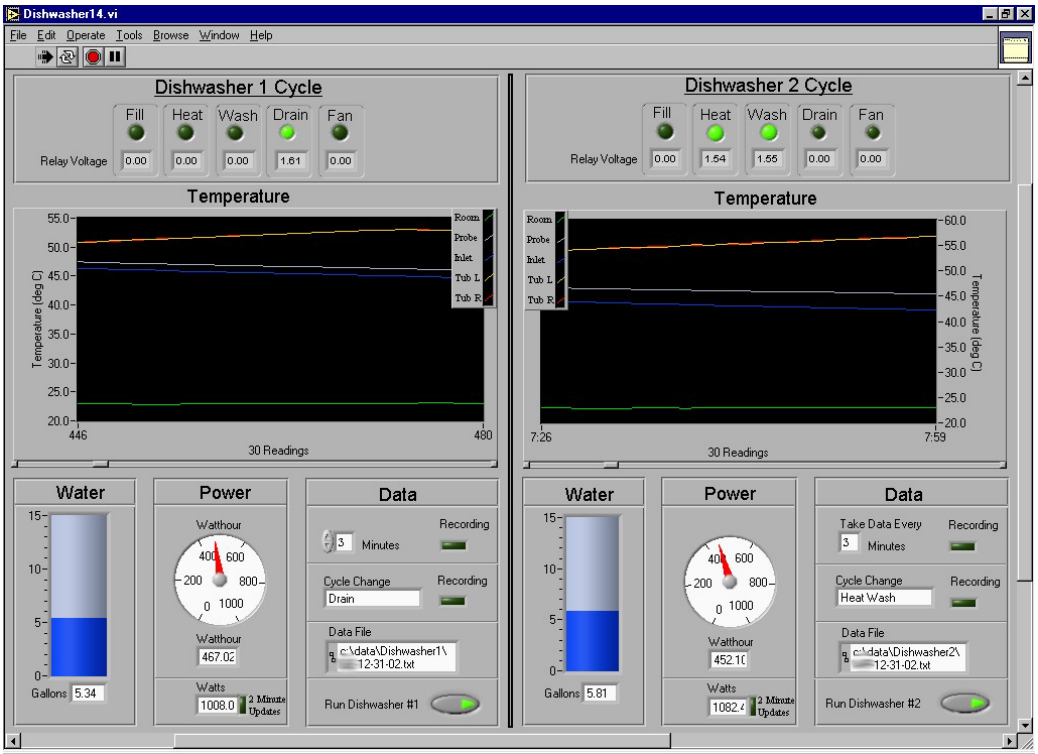

Figure 4: Graphical User Interface For Automated Data Collection

operator to view the operations of the dishwasher cycle. Voltage relays connected to all major components of the dishwasher are used to detect when the dishwasher is filling, heating, washing, draining, or drying. Indicators turn green when systems are in operation. Below the indicators is a temperature graph which plots temperatures for sensors located at the machine's water inlet, right and left sides of the dishwasher tub, room temperature, and for a movable probe. Below the plot is a fill indicator which shows the water consumption, a power indicator showing total watt-hours consumed and instantaneous watts consumption levels. Finally, data recording information is listed to allow the user to change sampling rates, to show when change or cycle operations are being recorded, and to specify the datafile being recorded. The program enables the automated testing of one or two dishwashers.

Tests of the heavy, medium, and light response for each dishwasher were carried out along with clean load tests. Figure 5 shows the heavy soil test load used for Dishwasher A and Dishwasher B, 4 soiled place settings for each dishwasher. The number of soil tests required for each dishwasher is determined using the 95 % confidence level required for reporting results, where variations in test results increase the number of tests required. The following sections present the measurements taken for water and energy consumption and discuss the calculations needed to obtain the energy factor and standby power consumption.

Figure 5: Photograph of soiled dishware used for testing two dishwashers

Water Consumption

The energy attributed to heating the water supply from 50 °F to the supply temperature of 120 °F has the largest impact on energy consumption. For this reason, the variability of the fill size and repeatability of fill patterns directly affect the Energy Factor rating. In these laboratory tests, Dishwashers A and B show an average fill size of 1.33 gal and 1.43 gal, respectively. The water consumption data for these dishwashers are plotted in Figure 6 and Figure 7. The data show variation in the fill size exists when using the AHAM DW-1 soiling procedure as well as when testing with a clean load.

For Dishwasher A, the light soil load invariably triggered a 4-fill cycle while both medium and heavy loads had responses that varied from 4 fills to 6 fills. This individual variation of fill size is a result of the system's response to turbidity measurements.

Dishwasher B shows more consistent responses to the standard soil loads with a 4-fill cycle response for all tests using the light and medium soil loads. There are large variations in the response to the heavy soil load (seen in Figure 7) which triggered the 6-fill response 6 times out of 10 tests, the 5-fill response 3 times out of 10, and the 4-fill response once. However, the water consumption for the 5-fill cycle is only slightly higher than that of the 4-fill cycle. Further analysis showed that fill sizes are not uniform due to a fill of approximately 0.2 gal that is used as needed to help clean the filter.

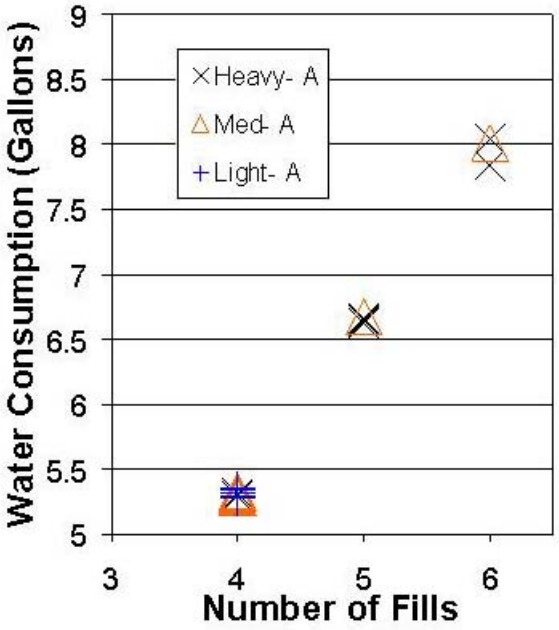

Figure 6: Water Consumption Results for Dishwasher A

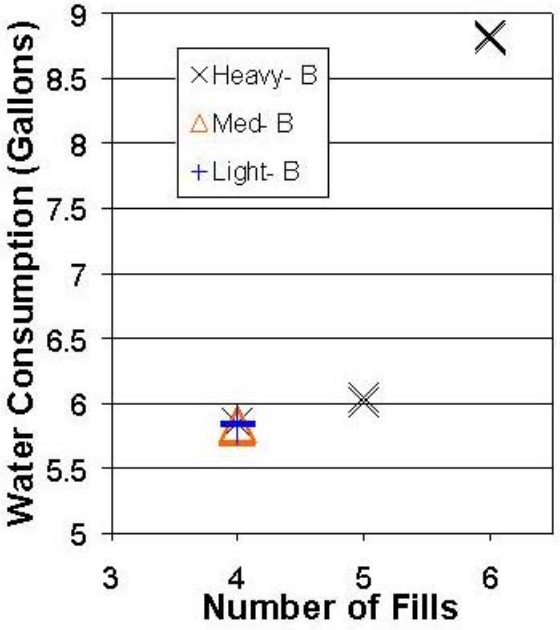

Figure 7: Water Consumption Results for Dishwasher B

Energy Consumption

The per-cycle energy consumption for a dishwasher is a composite of the water energy, the machine energy and the drying energy. The representative water use for the sensor normal cycle is calculated as the average of the water consumption for the heavy, medium, and light responses using the defined weighting factors. The water energy consumption is then calculated as the product of the representative water use, the nominal water heater temperature rise, and the specific heat of water. The representative machine energy consumption for the sensor normal cycle is determined as the sum of the product of the electrical energy consumption for the heavy, medium, and light response (excluding drying energy) and their respective weighting factors. Finally, the drying energy consumption is calculated as the average energy consumed during the drying portion of the three-level test. The total energy consumption is then calculated as the water energy plus the machine energy plus half of the drying energy. This represents the energy use for consumers that use the air-dry option 50 % of the time and is effectively an energy conservation credit for machines that provide consumers the ability to dry dishes without heat.

Figure 8 shows the energy consumption values for both dishwashers. The results are comparable for the two dishwashers though it is evident that the higher water consumption for Dishwasher B results in a higher total energy consumption.

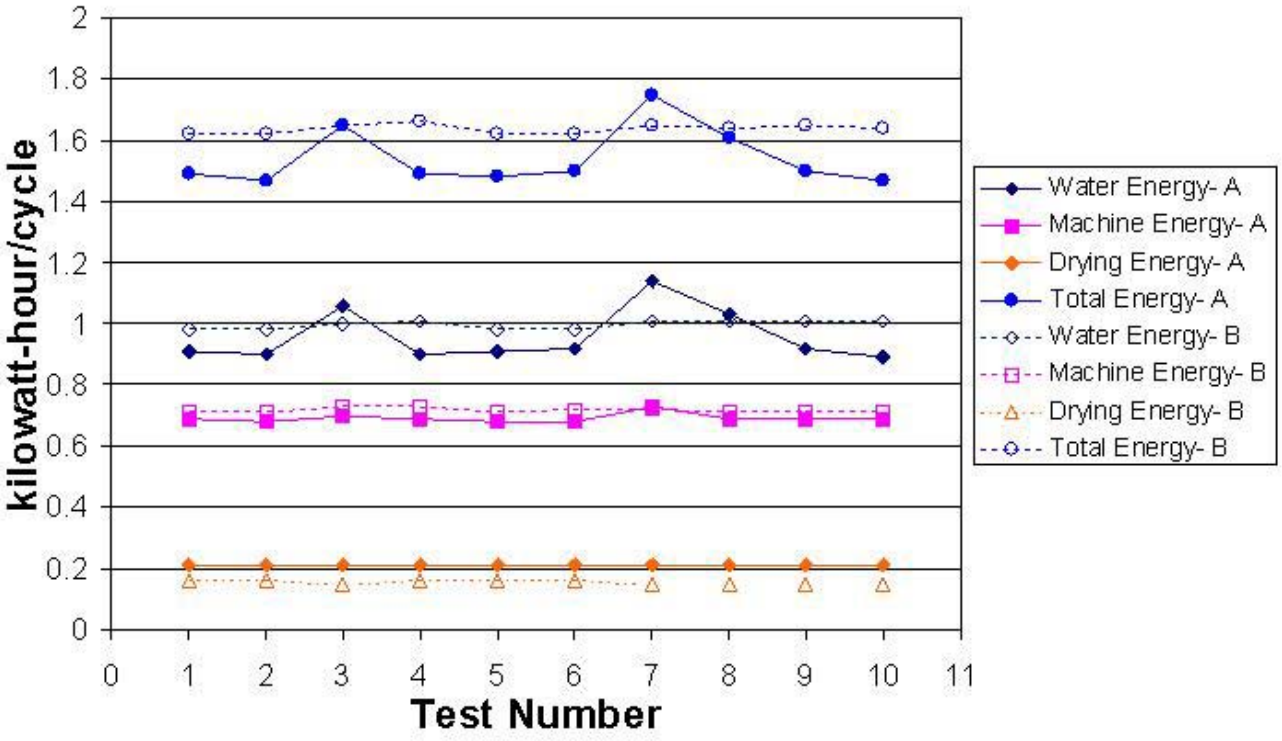

Figure 8: Plot of Energy Consumption for Soil tests

Energy Factor Calculation Results

The energy factor is simply the inverse of the energy consumption for the normal cycle. It does not take into account standby power consumption because it is a measure of the per-cycle energy efficiency. The Department of Energy sets the minimum energy efficiency standard at 0.46 cycles per kilowatt hour for standard dishwashers and 0.62 cycles per kilowatt hour for compact dishwashers. The energy factors calculated for each test are shown in Figure 9.

The uncertainty for these tests is shown in Figure 9 where error bars mark 3 standard deviations from the mean for the soil load tests. Dishwasher A shows more variation in its cycle responses. Because manufacturers must report the energy performance of each model, it is useful to determine the number of tests required to meet the confidence interval for reporting results. This is computed using Equation 3.

Equation 3 – Number Of Tests Required To Meet Confidence Interval

$n = (ts/d)^2$

where,

d is the allowable margin of error,
s is the standard deviation,
n is the number of tests, and
t is the percentile of a one-sided t-distribution. [8]

Setting d equal to 5 % of the minimum energy standard (as is used in the sampling plan for enforcement testing), one can determine if additional tests need to be conducted to satisfy the confidence requirements. Due to the variation in the test results, more than 10 tests are required to reach the 97.5% confidence for Dishwasher A. However, testing was

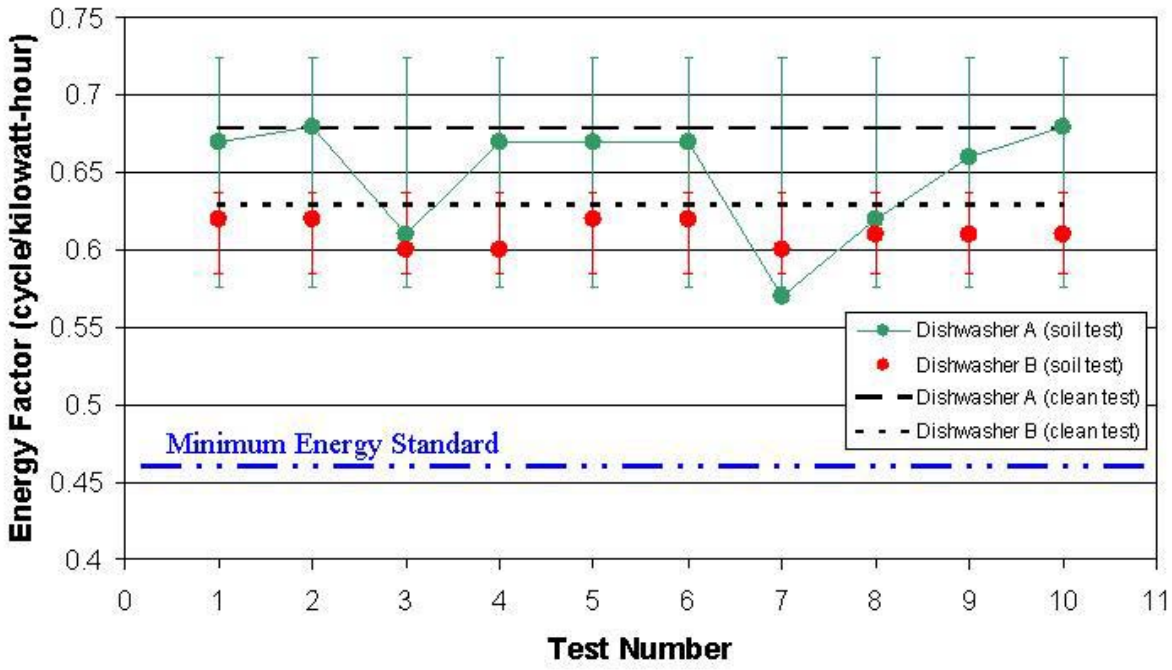

Figure 9: Plot of Energy Factors from Soil Tests

stopped at 10 tests because the purpose of this test is to validate the procedure and not to obtain the confidence levels needed to make representations for the energy efficiency of these models. For Dishwasher B, because there was very little variation in the results, the sample size for 97.5 % confidence was determined to be 9 tests. The results show an energy factor of 0.65 for Dishwasher A and 0.61 for Dishwasher B, both of which well surpass the minimum energy standard of 0.46 for standard models.

In the 6 clean load tests, the resulting energy factors were 0.68 for Dishwasher A and 0.63 for Dishwasher B. The results of the tests show only a slight decrease in the energy factor for the soil tests when compared to the original clean load tests.

Standby Power Use

The standby power use is taken as a direct measurement for dishwashers that have power variations of less than 5% of the maximum. For both of the two dishwashers used in the verification studies, the standby power was deemed stable. Instantaneous power measurement results were 2.2 W for Dishwasher A and 2.0 W for Dishwasher B. This represents a small, but significant level of energy consumption when considering the amount of time that dishwashers are in standby mode. According to the revised DOE test procedure, standby power use must be included in the calculation of the Estimated Annual Operating Cost.

CONCLUSIONS

The changes to the DOE test procedure provide a new method of test for soil-sensing dishwashers and add a test method for incorporating standby power into the Estimated Annual Operating Cost. Results from tests of two dishwashers using the revised test procedure show energy factors are 0.65 and 0.61 for dishwashers A and B, respectively. When these same dishwashers were tested with clean dishes the results were 0.68 and 0.63 cycles per kilowatt hour. Although the soil-based test results presented here show only a slight decrease to the energy factor, the introduction of a soil-based test presents a more realistic test of the sensor operation on which consumers can base purchasing decisions. The Department was not required to change the minimum energy efficiency standards since industry stated that no soil-sensing models would fail to comply when tested with the revised test procedure. It is also important to note that although these values report energy use, cleaning performance is not rated by the DOE test procedure.

The revised test procedure became effective September 29, 2003, allowing manufacturers to begin to make representations with results obtained using the revised test procedure. As of February 25, 2004, all manufacturers must use the revised test procedure. This test procedure is posted at http://www.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html.

ACKNOWLEDGEMENTS

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