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TEST PROCEDURE DEVELOPMENT FOR RESIDENTIAL DISHWASHERS

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The following is an edited version of a paper presented at the 50th Annual International Appliance Technical Conference, May 10 to 12, 1999, at Purdue University, West Lafayette, IN. It was named winner of the Dana Chase, Sr., Memorial Award, which is presented to the author(s) of the best paper delivered at the conference.

It has been recognized that the current Department of Energy (DOE)dishwasher test procedure is inadequate in testing soil sensing dishwashers. This paper discusses proposed changes to this test procedure, including several alternative testing options that were analyzed, with the goal of obtaining reliable efficiency factors which consumers could use in making purchasing decisions. Results of studies, conducted to determine the effect of the proposed revisions on calculated energy factors, are presented. In particular, tests of a soil sensing dishwasher, using the proposed test procedure and the current test procedure, are presented. Issues concerning manufacturers and energy conservation groups are also discussed.

Deficiencies in the Current Test Procedure

Design modifications in recent years and changing consumer dishwasher usage have established the need for additional test procedure revisions. In 1996, the National Institute of Standards and Technology (NIST) evaluated the current test procedure. The results proved the DOE test procedure to be an inadequate evaluation technique for comparing the performance of soil sensing dishwashers to conventional dishwashers [3]. Although no waiver request was submitted for soil sensing dishwashers, the results of the 1996 study deemed it necessary to change the test procedure, and specifically, to resolve unrealistic measurements of representative energy use. In addition, NIST identified several other aspects of the test procedure that needed improvement, such as updating references and improving repeatability between laboratories.

To ensure that all major issues were addressed, NIST and DOE met with members of the Association of Home Appliance Manufacturers (AHAM) to discuss the results of the initial review, additional ideas, and concerns regarding the test procedure. The comments resulting from these meetings, combined with discussions with energy conservation groups, were used to identify major issues and to formulate a proposal for resolving deficiencies in the test procedure [4].

Five major issues were identified:

- discrepancies in class designation for compact and standard dishwashers
- an unrealistically high energy factor for soil sensing dishwashers
- whether to include stand-by power use in energy consumption measurements
- the need to reevaluate the representative average use cycles
- improving test procedure clarity and repeatability.

The driving forces behind each issue are presented, along with a discussion of the proposed revisions to the dishwasher test procedure.

Compact vs. Standard Class Designation

The current dishwasher test procedure designates two product classes, standard and compact, that are defined based on the exterior width of the unit. According to Part 430.32(f), a compact dishwasher is less than 55.9 cm (22 in) in exterior width, while a standard dishwasher is "equal to or greater than 55.9 cm (22 in) in exterior width." One of the comments submitted by AHAM proposed that the definition of compact and standard dishwashers be based on washing load capacity. Under the current definition, NIST determined that two models are paradoxically labeled and one dishwasher is evidently misclassified, based on comparable models.

Whirlpool Corporation[1] (Benton Harbor, MI) manufactures an undercounter dishwasher under the Roper Brand, model RUD0800EB. This dishwasher has an eight-place-setting capacity, however, because it is only 45.7 cm (18 in) wide, it is classified as a compact dishwasher. General Electric(GE)[1] (Louisville, KY), also sells a dishwasher with a capacity of eight-place settings; however, the GE model GSM2100Z is an under-sink dishwasher that is 55.9 cm (22 in) wide with a full-size, bottom rack and a top rack that is only one-third the size of the bottom rack. This unit is labeled as a standard dishwasher.

The "DishDrawer" model manufactured by Fisher & Paykel[1], which can be purchased with one drawer or two drawers, is another dishwasher that presents a potential for mislabeling. This model is greater than 55.9 cm (22 in) wide and would therefore be labeled a standard dishwasher under the current class distinction. The two drawer system operates as two, stacked dishwashers sharing the same plumbing and washing system and can be run together or independently. The single-drawer system only has a loading capacity of approximately six-place settings; however, because of the width-based definition, the unit would be labeled as a standard dishwasher.

It is important that the definition of dishwasher class be a measure that proves useful to consumers when making purchasing decisions and that the dishwashers be held to the appropriate minimum energy standard for their intended class. The minimum energy standards developed for compact dish-

Table 1: Conventional Dishwasher Water and Energy Data

Cycle Type	Water Usage (Gallons)	Water Energy (kWh)	Machine Energy (kWh)	Total Energy (kWh)	Energy Factor (Cycle/kWh)	Current EAOC	Modified EAOC
Normal	10.02	1.7	0.58	2.28			
Trunc-Normal	10.01	1.68	0.47	2.16	0.45	$49.98	$40.98

Table 2: Soil Sensing Dishwasher Water and Energy Data

Cycle Type	Water Usage (Gallons)	Water energy (kWh)	Machine energy (kWh)	Total Energy (kWh)	Current Energy Factor (Cycle/kWh)	Modified Energy Factor (Cycle/kWh)	Current EAOC	Modified EAOC
Normal	4.84	0.81	0.62	1.43	—	—		—
Trunc Normal	5.29	0.89	0.55	1.44	0.70	—	$32.34	—
MAX Normal	9.45	1.59	0.92	2.50	—	—	—	—
Trunc	9.71	1.63	0.85	2.48	—	0.57	—	$32.36

washers have higher energy efficiency requirements than standard dishwashers. It is, therefore, critical that the class definition be specific enough so comparable dishwashers are identified in the same class and held to the appropriate minimum energy standard. It is, therefore, suggested that the definition of standard and compact dishwashers be based on loading capacity.

The Federal Trade Commission (FTC) defines a compact dishwasher as a counter-top dishwasher with a capacity of fewer than eight-place settings. A standard dishwasher is then defined as having a capacity of eight-place settings or more. To determine the effect of classifying an eight-place-setting capacity dishwasher as a standard dishwasher, it is necessary to see how such a dishwasher would be tested. In the existing standard, the test procedure designates that an eight-place-setting load, plus six-serving pieces, be used in dishwashers with water heating capabilities for tests of the normal cycle, at temperatures below 60°C (140°F). NIST finds a capacity-based definition to be appropriate for making the product class distinction. However, to ensure that all standard dishwashers have the capacity for the test load, it is proposed that a modified version of the FTC definition be adopted into the dishwasher test procedure. The new class designations [2], Section 430.32(f), would read as follows:

i. Compact Dishwasher (capacity less than eight-place settings plus six-serving pieces as specified in section 6.1.1 of AHAM Standard DW-1).

ii. Standard Dishwasher (capacity equal to or greater than eight-place settings plus six-serving pieces as specified in section 6.1.1 of the AHAM Standard DW-1).

The effect of this change would be that a few models, such as the GE model GSS1800Z and Whirlpool model RUD0800EB, would be re-classified as standard dishwashers and thereby decreasing the energy-factor requirement from 0.17 cycles/MJ (0.62 cycles/kWh) to 0.13 cycles/MJ (0.46 cycles/kWh). Conversely, those dishwashers not capable of handling the eight-place setting plus six-serving-piece load, such as the Fisher & Paykel modelDD601, would be required to meet an energy factor increased from 0.13 cycles/MJ (0.46 cycles/kWh) to 0.17 cycles/MJ (0.62 cycles/kWh).

Soil Sensing Technology in Dishwashers

Soil sensing technology has made the current test procedure ineffective in collecting representative energy and water consumption data. Under the current test procedure, the absence of soils in the test cycle triggers a shortened cycle for all adaptive dishwashers. Therefore, the energy factors obtained for these soil sensing models are very high and not representative of the performance when a soiled load is present. Some manufacturers have claimed lower energy factors (lower energy efficiency values) than those obtained using the current test procedure because they realize that the results are not representative of energy factors that consumers are likely to experience under normal use.

Various testing options were evaluated, including performance tests and field studies. It is believed that the most realistic measure of energy consumption is collected by running a performance test in conjunction with an energy test. This would give consumers the ability to balance efficiency and performance when making purchasing decisions. However, the problems associated with performance tests are significant. Apart from the issue of defining an appropriate soil load, there is a common problem of establishing repeatability and testing consistency between laboratories for performance based tests. In addition, there is a significant increase in test burden—once manufacturers introduced soils into a machine, the dishwasher could no longer be sold as "new."

The second option investigated is conducting field studies to obtain real world data regarding typical cycle times for soil sensing dishwashers. Test burden would not be high for those manufacturers who routinely collect such data for analysis; however, it would be difficult to establish a test population that would be uniform for all manufacturers. It was thus necessary to find an alternative test procedure for soil sensing dishwashers that would provide reliable data without greatly increasing test burden or cost to manufacturers.

The DOE proposes to resolve this problem by modifying the definition of dishwashers to specify two types of dishwashers, conventional and soil sensing, and adding new definitions for these two types. A method could then be developed to collect representative energy and water consumption values for soil sensing dishwashers. AHAM suggested a method to collect representative data by forcing soil sensing dishwashers into a maximum normal-response cycle. Manufacturers would test a dishwasher in accordance with the current DOE test procedure in the normal cycle and record the energy and water consumption values for the "minimum sensor normal" as M_{min} and V_{min}, respectively. OEMs would then adjust the dishwasher cycle to reflect maximum soil loading and repeat the test, recording the energy and water consumption values for the "maximum sensor normal" as M_{max} and V_{max}, respectively. Each manufacturer would provide keystroke instructions on how to force a dishwasher into a maximum-sensor normal response.

The next step would be to weight energy and water consumption values, according to the percentage of people who do and do not pre-treat their dishes. The electrical energy consumption per cycle for the machine is expressed in kWh per cycle and defined as:

$$M = [M_{min} \times (P) + M_{max} \times (1 - P)]$$

where, P equals the fraction of people who pre-treat dishes and (1-P) equals the fraction of people who do not pre-treat dishes.

Similarly the water consumption per cycle for the machine is expressed in kWh per cycle and defined as:

$$V = [V_{min} x (P) + V_{max} x (1 - P)]$$

using the same weighting factors (P and 1-P).

This suggestion has been reviewed and the DOE proposes to adopt it into the test procedure with changes. The DOE proposes to include a clause stating that if a manufacturer does not provide a way to artificially force a maximum response, a soil load shall be introduced, as specified in the AHAM DW-1 performance test to obtain the maximum energy consumption.

A second matter relates to the percentages to be used in pro-rating the E_{min} and E_{max} values (energy consumption). It was proposed by AHAM that the Soap and Detergent Association (SDA) supply data based on surveys of the number of persons who pre-treated their soiled dishes with water and the number of persons who scrape the soiled dishes or load them directly into the dishwasher. The supporting argument for the use of this data is that pre-treated dishes have lower soil levels that trigger lower energy consumption in soil sensing dishwashers. Manufacturers have claimed that in studies, persons who pre-treat their dishes have dishwashers that operate in the minimum cycle. Conversely, it is believed that for persons who do not pre-treat their dishes, the high soil level will trigger a maximum response. The SDA report, based on 1995 data, states that 79 percent of the people surveyed pre-treat their dishes (using water to rinse scrub or soak the dishes) and 21 percent of those surveyed do nothing or merely scrape their plates. The SDA also noted that because these results are based on consumer perception and interpretation, there are inherent uncertainties. The SDA stated that the data should not be used as quantitative data representative of consumer practices [5].

The DOE agrees that given the disclaimer within the SDA report and other expressed concerns, the 1995 SDA data is not sufficient for determining the percentages of pre-treatment. For this reason, we collected additional data from a 1989 Proctor and Gamble survey, showing 73 percent pre-treating and 27 percent not pre-treating, which supports AHAM's statement that the number of persons who pre-treat their dishes has increased over the past 10 years. Another dishwasher-user survey conducted in 1999 by Dethman and Associates for the Northwest Energy Efficiency Alliance and the Consortium for Energy Efficiency found that 63 percent of respondents rated their dishes as "somewhat clean," with small particles of food left, or "very clean," with all or almost all of the food gone. However, when Dethman and Associates calculated a cleanliness score based on a series of questions, the results showed 83 percent of the dishes were rated as "somewhat clean" or "very clean." This highlights the subjective nature of these surveys and the variations in the way the questions were presented. This data was therefore used as a qualitative indication and not as a quantitative measure of consumer practices.[6]

Lacking more precise data at this time, the DOE is proposing to use the following compromise figures as a reasonable surrogate for average soil loading: 70 percent to represent the percentage of the population who pre-treat their dishes and 30 percent to represent the percentage who do not pre-treat their dishes. Since the determination of these percentages is critical to the test procedure formula for the soil sensing dishwashers, the DOE is especially interested in receiving comments on the proposed percentages. Once this data is presented, the DOE intends to review the values and adjust the weighting factors as needed.

Stand-By Power

The existing test procedure was only designed to measure energy consumption during the test cycle. However, the drive to provide more advanced features in the high-end models (e.g. innovative soil sensing control schemes and displays) caused a shift from mechanical controls to electro-mechanical controls using transformers. Using transformers, the dishwasher consumes energy even when the dishwasher is not running a cycle (stand-by). The transformer provided power to the controls needed for the timers and display lights, and allowed manufacturers to store information about previous cycles to be used in the adaptive control schemes. In one such model, the stand-by energy use was measured to be 7.09 J/s (7.09 W). When pro-rated for the estimated amount of time the dishwasher is on stand-by, the resulting stand-by energy use is 211.3 MJ/year (58.7 kWh/year).

The second generation of controls shows a decrease in the use of transformers, as microprocessors are introduced. These microprocessors continue to require stand-by power but on a smaller scale. AHAM reports that on average, electronics packages with a transformer consume 6 J/sec (6 W), mid-range electronics consume 3 J/s to 3.5 J/s (3 W to 3.5 W), and low-power electronics consume as little as 1.5 J/s to 2 J/s (1.5 W to 2 W). When pro-rated for the year, the average energy use for the mid-range and low-power electronics is estimated to be 97.9 MJ/year and 52.6 MJ/year, respectively, (27.2 kWh/year and 14.6 kWh/year) and are obtained as follows:

Representative Time in Stand-by Mode:

- 8,760 hours/year - (264 cycles/year * 90 minutes/cycle) = 8,364 stand-by hours/year

Annual Energy Consumption in Stand-By Mode:

- Transformer: (8,364 stand-by hours/year *7.09 J/sec) = 211.3 MJ/year
- Mid-range: (8,364 stand-by hours/year * 3.25 J/sec) =97.9 MJ/year
- Low-power: (8,364 stand-by hours/year * 1.75 J/sec) =52.6 MJ/year

This issue of stand-by power, also known as "invisible" energy use and energy "leaking," affects many residential appliances that have electronics incorporated into their design. Although it is recognized that the efficiency is improving, the market may see an increasing percentage of models that offer electronics packages and thereby consuming stand-by power. The dishwasher test procedure is designed to collect representative data for total annual energy use to calculate the estimated annual operating cost (EAOC) which consumers can use to make their purchasing decisions. This issue must be addressed for all appliances that have the potential for stand-by power consumption, including dishwashers. The DOE decided to address this issue in a Notice of Proposed Rulemaking (NOPR) for all such appliances to establish uniform measurement procedures rather than to address each test procedure individually.

Representative Average-Use

Historically, the Procter & Gamble (P&G) survey data has been used as the sole gauge of consumer dishwashing practices. In 1983, the DOE amended the dishwasher test procedure to reduce the representative average-use from 416 cycles per year to 322 cycles per year based on a P&G survey of consumer dishwashing practices. That survey was based on data collected prior to 1982. New survey data was solicited from the SDA for more recent years. In response, the SDA provided comparable survey results for selected years from 1986 to 1996. Averaging the survey results for this decade of survey data indicates that the number of cycles consumers use on a yearly basis has decreased from the current value of 322 cycles per year to 264 cycles per year. The DOE proposes to use this data to support a revision of the representative average use to 264 cycles per year. This change effectively lowers the estimated annual operating cost (EAOC) which is the product of the representative average-use cycles, the energy consumption (kWh/cycle), and the representative average unit cost in dollars per kWh.

Improving Test Clarity and Repeatability

The DOE also proposes that the tolerance for the dishwasher and ambient temperature in testing conditions be tightened from the current range of between 21.1°C and 29.4°C (70°F and 85°F) to between 21.1°C and 26.7°C (70°F and 80°F). The average total energy consumption of a dishwasher tested at 29.4°C (85°F) with a standard test load was measured by NIST to be 17.6-percent lower than the same test of the normal cycle tested at 21.1°C (70°F). This effect could cause significant variations in results between laboratories and should be minimized. It is noted that AHAM performance tests are conducted in the temperature range of 21.1°C and 26.7°C (70°F and 80°F).

In another effort to increase the repeatability of testing between laboratories, the DOE proposes to incorporate more detailed requirements for test chamber installation and that the changes be adopted into the dishwasher test procedure, using the wording proposed by AHAM. The revised installation instructions will support uniformity among testing laboratories without a significant addition to the test burden. They are:

2. Testing conditions: 2.1 Installation. The dishwasher must be installed in accordance with the manufacturer's instructions. Under-counter and under-sink dishwashers must be installed in a test area as follows: A standard or compact under-counter dishwasher must be tested in a rectangular enclosure constructed of nominal 9.5mm (0.37 in) plywood painted black. The enclosure must consist of a top, a bottom, a back, and two sides. If the dishwasher is provided with a countertop as part of the appliance, the top must be omitted. The enclosure must be brought into the closest contact with the appliance as the configuration of the dishwasher will allow.

It is a common industry practice to run a conditioning cycle for dishwashers before conducting a test. This ensures that the water lines and sump area of the pump are primed, which better approximates normal household conditions. The DOE proposes that this should be included as part of the test procedure, to establish consistency between tests and laboratories.

To clarify the test procedure and increase repeatability, the DOE proposes to introduce a new section, "Instrumentation," to consolidate all measurement specifications and to base tolerances on nominal values. Within this section, the DOE proposes to add specifications for temperature measurement devices which were previously not stated.

Test Results and Discussion

NIST tested two dishwashers using the proposed test procedure to determine the effect of the revisions: a conventional model with a predetermined wash sequence and a soil sensing model with adaptive controls to reduce energy consumption.

All tests were conducted using 48.9°C (120°F) inlet water and an eight-place setting plus six-serving-piece test load. The conventional dishwasher was tested in the normal and truncated-normal cycle. The soil sensing dishwasher was tested in the normal and truncated-normal cycle followed by two tests of the maximum-normal and maximum-truncated-normal cycles. A sequence of key strokes was provided by the manufacturer to force minimum and maximum normal responses. This test was conducted twice and the results averaged.

The results of testing the conventional dishwasher and the soil sensing dishwasher are presented in Table 1 and Table 2, respectively. The modifications discussed in this paper do not affect the general testing requirements for conventional dishwashers. However, by updating the representative average use cycles to 264, the calculated EAOC is effectively reduced by 18 percent, from $49.98 to $40.98.

For the soil sensing dishwasher, the testing requirements are greater. The current test procedure calls for testing the normal and truncated-normal cycle. The current EAOC calculation is the product of: 1) the energy consumption in the normal and truncated-normal cycle 2) the cost of energy, $0.25/MJ ($0.07/kWh), and 3) the representative average use cycles, 322. The result is an estimated annual operating cost of $32.34. In soil sensing dishwashers, this only represents the dishwasher's minimum response.

For the revised test procedure, the maximum response energy consumption is also measured. In addition to updating the representative average use to 264 cycles per year, a 70/30 ratio was used to combine the minimum and maximum energy use values, respectively. The result is a negligible increase in the EAOC, from $32.34 to $32.36.

All standard dishwasher models are required to establish compliance with the minimum energy standard of 0.13 cycles/MJ (0.46 cycles/kWh). For the conventional dishwasher, the calculated energy factor, 0.125 cycles/MJ (0.45 cycles/kWh), is slightly lower than the standard. The reason this particular test is lower than the standard is believed to be because the water pressure used during the tests was 255 kPa (37 psi). Although the allowable pressure range is 223 kPa to 258 kPa (32.5 psi to 37.5 psi), dishwashers with timer-controlled water valves (such as in this test unit) are prone to higher water usage at greater water pressures.

For the soil sensing dishwasher, the energy factor is dependent on the weighting factors used for minimum and maximum energy use. Additional calculations were made to see the effect of changing the percentage of pre-treated loads on the resulting energy factor. Table 3 shows how the energy-fac-

Table 3: Effect of Pre-Treatment on the Energy Factor Calculation

Load not Pre-treated	MAX Energy Use	Weighted Load (A)	Pre-Treated Load	MIN Energy Use	Weighted Load (B)	Energy Factor (1/A+B)
100%	2.49	2.49	0%	1.44	0.00	0.40
90%	2.49	2.24	10%	1.44	0.14	0.42
80%	2.49	1.99	20%	1.44	0.29	0.44
70%	2.49	1.74	30%	1.44	0.43	0.46
60%	2.49	1.49	40%	1.44	0.57	0.48
50%	2.49	1.25	50%	1.44	0.72	0.51
40%	2.49	1.00	60%	1.44	0.86	0.54
30%	2.49	0.75	70%	1.44	1.00	0.57
20%	2.49	0.50	80%	1.44	1.15	0.61
10%	2.49	0.25	90%	1.44	1.29	0.65
0%	2.49	0.00	100%	1.44	1.44	0.70

A= Load not pre-treated* Max Energy Use
B= Pre-Treated load* Min Energy Use

tor calculation is affected for an assumed range of pre-treated loads. Data printed in bold indicates the soil sensing dishwasher compliance with the minimum energy standard for an assumed pre-treated load as low as 30 percent.

Test results in this paper have a combined standard uncertainty of 5.2 percent.

Conclusion

The review of the DOE dishwasher test procedure identified several deficiencies. Through testing at NIST and discussions with members of AHAM and energy conservation groups, five major issues were identified:

- discrepancies in class designation for compact and standard dishwashers
- an unrealistically high energy factor for soil sensing dishwashers
- whether to include stand-by power use in energy consumption measurements
- the need to reevaluate the representative average use cycles
- improving test clarity and repeatability.

Several modifications were proposed to address these issues. A new definition was developed to classify compact and standard dishwashers based on capacity rather than width. A method of obtaining a "real-world" estimate of energy consumption in soil sensing dishwashers was presented by AHAM. The method involves forcing a minimum- and maximum-normal response, measuring the energy consumption, and weighting the values with an estimate of consumer pre-treatment practices.

On the issue of stand-by power, tests of a soil sensing dishwasher showed an energy consumption of 7.02 J/sec (7.02 W) which equates to 211.3 MJ/year (58.72 kWh/year). However, this stand-by energy use is expected to drop dramatically with the introduction of low-power electronics in new designs. The DOE recognizes that all energy use should be included in the estimate for annual energy consumption for all appliances and has decided to address this issue in a combined proposed rule for all appliances that consume stand-by power.

Laboratory tests were conducted on two residential dishwashers: a conventional and a soil sensing model. Tests were conducted once according to the current DOE test procedure and a second time with the modified test procedure. Test results showed that the modified test procedure caused an 18-percent reduction in the estimated annual operating cost (EAOC) for the conventional dishwasher due to the reduction in representative average use cycles. No significant change in the EAOC was seen for the soil sensing dishwasher due to the weighting factor for the maximum longer wash cycle balanced with the change in representative average use.

The modifications discussed in this paper are intended to enable a realistic comparison of energy consumption results for conventional and soil sensing dishwashers. By making a better class distinction, establishing more real-world test cycle for the soil sensing dishwasher, updating consumer use values, and increasing test repeatability, it is anticipated that the modified test procedure will accomplish these objectives. AE

Note

[1]The use of manufacturers' names and product brands does not imply endorsement by the National Institute of Standards and Technology.

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