Soil Removal in Relation to Total Work Input: Calorimetric Investigation in Full-Size Washers

L. LOEB and **R.O. SHUCK** Major Appliance Laboratories,
General Electric Co., Louisville, Kentucky 40225

ABSTRACT

A simple, straightforward method, utilizing the concepts of classical adiabatic calorimetry, is described for the direct measurement of total energy delivery to a functional wash system. For this work a full-sized vertical axis automatic washer was modified for utilization as a calorimeter. The application of this equipment, and the rationale of this approach in studying the energetics of soil removal are discussed. To illustrate this technique, the effects of agitation frequency and detergent concentration on power consumption by the wash system are considered.

INTRODUCTION

The rationale of the calorimetric technique for measuring energy delivery to clothes washing systems has been previously discussed (1). In this earlier work the application of calorimetric techniques to the study of detergent processes was explained as follows. Consider a thermally isolated wash system containing a known volume of detergent solution and a known weight of soiled fabric. If, then, a given amount of mechanical energy is delivered into this isolated system, the heat content must be increased by an amount dependent only on the mechanical energy delivered. The measurement of such changes in heat content of the system requires only that a method be available for accurately following temperature changes during the mechanical agitation period, that the heat equivalent of the total system be known, that there be no appreciable exchange of heat between the bath and its surroundings, and that any heat effects associated with the interaction of the fabric substrate and the detergent bath be dissipated during an equilibration period prior to the agitation period. The measurements presented earlier were all obtained in a small Dewar type calorimeter using the Terg-O-Tometer as a means for providing agitation of the wash load. In this bench scale unit the bath volume was limited to about 1 liter and the load size to about 40 g of fabric. In view of the extreme dimensional differences it was difficult to extrapolate the earlier results to full size washing units.

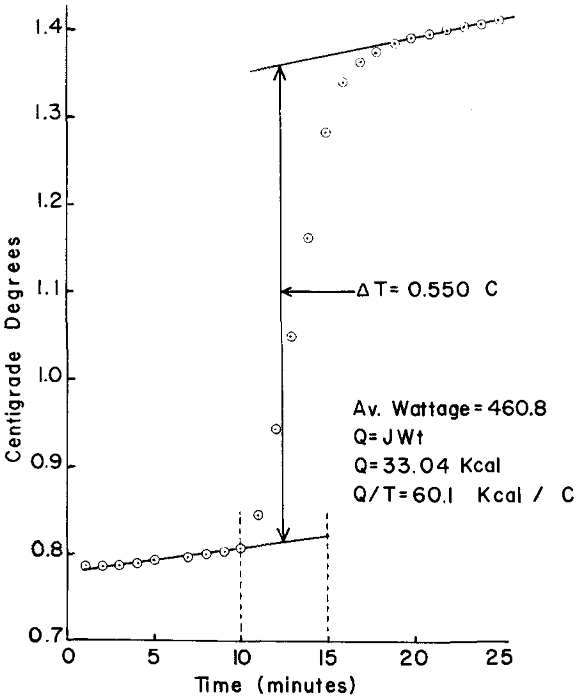

FIG. 1. Typical time-temperature plot from heat equivalent determinations.

A full size vertical axis home washer was, therefore, modified for utilization as a calorimeter. A description of this unit is given together with examples of the type of information obtainable by use of calorimetric measurements in this full-size home clothes washer.

DESCRIPTION OF MACHINE CALORIMETER

For this work a full size GE Model 850B1 clothes washer was modified so as to make it usable as a calorimeter. The main modifications were as follows: (a) A nonperforated basket was substituted for the production basket. (b) The annular space between basket and tub was completely filled with a closed cell urethane foam. (c) The cover and removable lid were insulated with shaped slabs of urethane foam. (d) To prevent heat transfer from the motor and drive mechanism, the drive tube was isolated from the bath by insertion of a Textolite tube cover. The modifications listed above obviously eliminated the recirculation and extraction spin functions normal for this type of washer.

In using the calorimetric technique for measuring energy input to the wash system, two basic pieces of calibration data are required: (a) The heat equivalent of the total calorimeter system in calories per °C, and (b) The temperature rise rate for the agitation rate and load size under study in °C/min. The product of these two items gives the power input in calories per minute; the product of power and total wash time in minutes gives the total energy input during the washing cycle.

In determining the heat equivalent of the machine calorimeter it was necessary to provide an accurately known amount of heat to the bath and to measure accurately the temperature rise produced. For this deter-

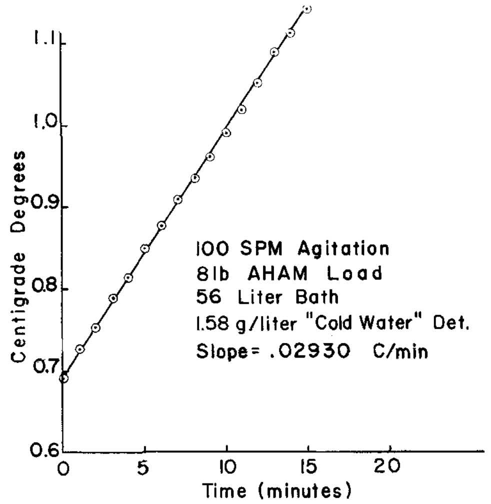

FIG. 2. Typical time-temperature plot from power consumption determinations.

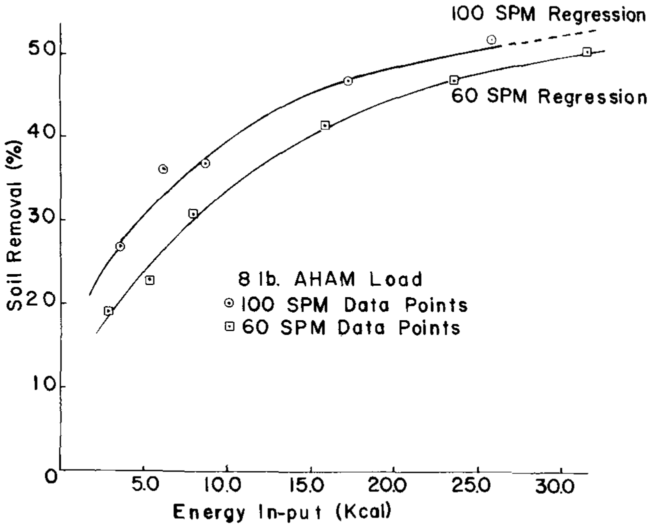

FIG. 3. Soil removal as a function of total energy input for two different agitation rates.

mination, a 500 w Vycor immersion heater was employed as the heat source. The power input to the heater was measured with a Type P-3, GE single-phase watt meter. For work with an 8 lb clothes load the machine was filled with 56.0 liters of distilled water giving a 28.6 cm water level. The detergent employed was a low foam, granular product based on a combination of anionic surfactants and intended for cold water washing. The detergent was added in sufficient amount to give a concentration of 0.158% by weight. The detergent bath with the clothes load in place was allowed to equilibrate for 30 min with temperature measured at 1 min intervals with an immersed Beckmann thermometer. The heater was then energized for exactly 300 sec and the wattage recorded at 1 min intervals throughout the heating period. During both the equilibration and heating periods the wash system was agitated continuously at a slow and constant rate to prevent temperature stratification. To facilitate accurate temperature rise measurements, it was necessary to keep the machine calorimeter in a constant temperature room (23 ± 1 C). In addition, for all runs the initial temperature of the wash bath was adjusted to within ± 1 C of ambient. A typical time-temperature plot is shown in Figure 1. For the run shown, the average power during the 300 sec heating period was 460.8 w; the temperature rise was 0.550 C. The heat input was calculated to be 33,040 calories and the heat equivalent of the system to be 60.1 Kcal per °C.

A series of determinations of the heat equivalent was made with 56.0 liters of distilled water, 88.5 g of detergent, and varying weights of cotton fabric (450 to 1700 g). As would be expected, the measured heat equivalent of the system was not appreciably dependent upon the weight of the added fabric load. This result is reasonable since the calculated contribution of 1700 g of cotton is only about 500 cal per °C. This follows from the assignment of a value of 0.29 cal/g/C for the specific heat of cotton as measured by Magne, et al. (2). The average value for the heat equivalent for the system described above based on 14 replicate runs was 59.08 ± .52 Kcal/C. This value must, of course, be redetermined if the bath volume or mechanical parameters of the system are modified.

TABLE I

Energy Input Rate for 8 Lb. AHAM Load

Stroke rate		Energy input rate, Slope of time-temp line, C/min
Nominal	Actual	
100	101.3	.02875
100	101.3	.02887
100	101.3	.02930
Average		.02897
60	58.0	.008857
60	58.0	.008803
Average		.008830

RESULTS

The calorimetric technique can be used to study the effect of a wide range of physical parameters on power consumption during washing. For example, the effects of load size, agitation rate, fabric structure and fiber make-up, and the role of detergent on power consumption can be studied. The results given in the present report will be limited in the main to an illustrative example on effect of agitation rate and to some work on detergent effects.

Effect of Agitation Rate on Power Consumption

The energy input rate was determined for an 8 lb. AHAM mixed cotton load in baths containing 1.58 g/liter of the granular cold water detergent. For work with this detergent, the 56.0 liter wash bath was adjusted to an initial temperature of 23.4 ± 1 C for each run. The bath containing the specified weight of fabric, water and detergent was agitated at the desired stroke rate and the temperature was measured at 1 min intervals. The temperature vs. time plots for all of these runs were linear; a typical plot at 100 SPM agitation is given in Figure 2. The slopes of these lines were determined by the method of least squares and are shown in Table I.

Soil removal runs were made utilizing the same 8 lb. AHAM load that was used in the determination of the energy input rates. The total energy input for each of the soil removal runs was calculated from the product of the

TABLE II

Soil Removal and Calculated Energy Input for 8 Lb. AHAM Cotton Loads

Agitation rate, SPM	Duration of wash, min	Total energy input, Kcal	Soil removal	
			Average $\bar{X}_{10}$	Std. Deviation $\pm\sigma_{10}$
100	2.0	3.42	26.5	6.7
100	3.5	5.99	35.7	6.7
100	5.0	8.56	36.7	5.4
100	10.0	17.1	46.4	2.9
100	15.0	25.7	51.2	3.9
60	5.0	2.61	18.8	7.8
60	10.0	5.22	22.6	12.9
60	15.0	7.83	30.6	9.4
60	30.0	15.6	41.1	9.1
60	45.0	23.5	46.3	11.4
60	60.0	31.3	50.0	9.6

TABLE III

Power Consumption of "No Load" Baths With Varying Detergent Concentration

Detergent concentration, wt %	Energy input rate, C/min	Power consumption, cal/min	Surface tension, dynes/cm
0	.0180	1005	69.3
.04	.0159	887	27.7
.08	.0162	904	27.4
.12	.0164	915	28.2
.16	.0160	893	29.1
.20	.0166	926	29.3
	$\bar{X}_5 = .0162 \pm .0003$	$\bar{X}_5 =$ 905	

appropriate energy input rate value from Table I, the heat equivalent of the system, and the duration of the wash run in minutes. In each case, the total energy input was controlled by varying the wash time. Ten USTC cotton soil cloth swatches were affixed to garments in the 8 lb. loads.

The soil removal values were calculated in the usual manner via the Kubelka-Munk equation (3) with reflectance determined before and after washing using a Gardner CIE Automatic Colorimeter. An excellent summary of this calculation procedure is given by Harris, et al. (4). The colorimeter was equipped with Corning No. 3389 Noviol filters to eliminate any UV radiation from the light source.

The soil removal values and calculated total energy inputs are summarized in Table II. The soil removal results for the 8 lb. AHAM loads are shown as a function of total energy input in Figure 3.

The Role of Detergent on Power Consumption

To determine the role, if any, of the detergent on power consumption, several additional machine calorimeter runs were made. In the first series of runs, increasing amounts of detergent were added to a fixed volume water bath containing no fabric load; the power consumption data for this series are given in Table III. In addition to the calorimetric measurements on these baths, the surface tensions of these solutions were also determined at 25 C using the Cenco-Du Nouy ring tensiometer. The power consumptions and surface tension data for these "no load" runs are summarized in Table III.

A similar series of runs was then made which was identical to the first series in all respects except that an 8 lb. cotton shirt load was included. Again, increasing concentrations of the cold water detergent were added to the bath. The power consumption data for these runs in the presence of the fabric load are summarized in Table IV.

DISCUSSION

The data of Table I show that energy input is strongly dependent on agitation rate. The energy input at the higher stroke rate was found to be 3.28 times that at the lower. According to the work of Tuzson and Short (5) the power delivery of a reciprocating agitator should be proportional to the cube of the product of oscillation frequency and the arc angle,

$$P=K(\alpha\phi)^3$$

where α is the arc angle in radians and ϕ is the oscillation frequency in cycles per second. For the present work on 8 lb. loads in a full size machine the power delivery is dependent on agitation frequency to the 2.13 power rather than the theoretical value of 3.0.

TABLE IV

Power Consumption for 8 Lb. Cotton Load in Bath With Varying Detergent Concentration

Detergent concentration, wt %	Energy input rate, C/min	Power consumption, cal/min
0	.0315	1791
.04	.0320	1820
.08	.0312	1774
.12	.0309	1757
.16	.0314	1786
.20	.0307	1746
	$\bar{X}_6 = .0313 \pm .0005$	$\bar{X}_6 = 1779$

Tuzson and Short developed their equations from consideration of the hydrodynamics of homogenous fluid baths. The present calorimeter measurements were made on highly loaded, non-homogenous baths at a bath to fabric ratio of 15.5:1. In consideration of the system differences, the agreement in the frequency exponent is considered reasonably good. Previous unreported work obtained in the Terg-O-Tometer calorimeter at a bath to fabric ratio of 40:1 gave a frequency exponent of 2.89. It, thus, appears that the cubic relationship is valid in the limiting case for unloaded baths.

Consideration of the data in Table III on detergent effects shows that in the absence of detergent, the power consumption was significantly higher than for any of the baths containing detergent. There was no significant variation in power consumption among the baths containing 0.04% to 0.20% detergent. The average power consumption value for the five baths with detergent was 905 cal/min which is 100 cal/min lower than the detergent free bath. Similarly there was no variation in the measured surface tension among the five detergent-containing baths. It seems reasonable that the higher power consumption for the detergent-free bath is related to the work expended by the agitator in disrupting the high energy liquid-air interface.

The above-mentioned detergent effect was noted for baths containing no fabric load. As shown in Table IV, power consumption measurements in the presence of a reasonable size fabric load indicate no dependence on detergent concentration. Apparently the fabric load disrupts the free liquid surface to such an extent that the surface energetics of this interface are no longer of any consequence.

Additionally, it is of interest to compare the data given in Tables III and IV with regard to energy input. As seen in these Tables, the energy consumption of the wash system is much greater with the cotton load present. Other experimental calorimetric data, not presented in this report, have shown the energy consumption of the wash system to be strongly dependent on the size of the fabric load. The increased power consumption noted here for the bath with the 8 lb. load is in accord with other data on power consumption as a function of load size.

The limited data presented are to be considered only as examples of the applicability of this technique. In general, it appears that much useful information on the energetics of a wide variety of detergency processes should be obtainable through utilization of the calorimetric approach.

REFERENCES

1. Loeb, L., and R.O. Shuck, JAOCS 46:299 (1969).
2. Magne, F.C., H.J. Portas and H. Wakeham, J. Amer. Chem. Soc. 69:1969 (1947).
3. Kubelka, P., and F. Munk, Z. Tech. Physik 12:593 (1931).
4. Harris, J.C., M.R. Sullivan and L.E. Weeks, Ind. Eng. Chem. 46:1942 (1954).
5. Tuzson, J., and B.A. Short, Textile Res. J. 30:989 (1960).

[Received June 12, 1970]