The sum of the squared partial derivatives,

$$\left(\frac{\delta C}{\delta y_1}\right)^2 + \left(\frac{\delta C}{\delta y_2}\right)^2 + \left(\frac{\delta C}{\delta y_3}\right)^2 = M,$$

is a multiplier characterizing the influence of the y_1, y_2, y_3 values upon the variance of the C value. Then,

$$S^2_C = M \cdot S^2 y.$$

A most simple and demonstrative physical model of a complicated process such as washing was used in this work to derive all these equations. It is a matter of experience to accept or refuse this model.

The acquired results shown in Part II of this work (*JAOCS* 58:1015) and the analysis of the experimental application of the discussed relations support the opinion that our assumptions are fully justifiable for the kinds of soils and fabrics used.

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A New Method for Evaluating the Washing Power of Washing Agents for Cotton Fabrics: II. Evaluation of the Method's Usability

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ABSTRACT

A method of evaluating washing effectiveness based on the analysis of the effect of the number of washings on the degree of cleaning was verified in this work. Four commercially available washing agents were tested. The method proved useful for evaluating the degree of cleaning of cotton fabrics and for classifying washing agents according to their washing power. The method is simple, economic and effective.

INTRODUCTION

According to many authors (1-4), it is necessary to perform repeated washings of the same fabric in order to obtain reliable information concerning the effectiveness of any washing agent. The results acquired, e.g., by Tijskens (3) show that repeated washings clean the fabric only to a certain degree. The degree of cleaning achieved is characteristic of the given kind of soil, the washing agent used and the fabric. A similar outcome was anticipated from the analysis of light scattering phenomena on the fabric described in previous work (5).

The purpose of this work was to verify the described method of evaluating the cleaning power of various kinds of washing agents. The method is tested to determine if the results provide satisfactory reproducibility. The method also provides a means to classify washing agents with respect to their cleaning power. The use of this method will make the determination of examined parameters faster, easier and more economical. The experiments allowing evaluation of the method's usability are described next.

EXPERIMENTAL

Materials and Apparatus

The method described was tested on the following standard soiled test fabrics: EMPA 101—pigment/grease-soiled; EMPA 111—blood-soiled; EMPA 116-pigment/grease/protein-soiled; EMPA 211—unsoiled control fabric sample, used as a whiteness standard (100%) for the EMPA 101 fabric; EMPA 302—unsoiled control fabric sample, used as a whiteness standard (100%) for the EMPA 111 and 116 fabrics.

The effectiveness of the following washing agents was tested: A—high-foaming synthetic powder without perborate; B—high-foaming synthetic powder with perborate; C—regulated foam synthetic powder with perborate; D—soap/synthetic powder without sodium polyphosphate; The detergents had the following compositions:

Composition (%)	A	B	C	D
Synthetic surface-active agent	20.0	20.0	8.0	5.0
Soap	2.0	–	6.5	34.5
Sodium polyphosphate	35.0	25.0	26.5	–
Soda	12.0	15.0	22.0	33.0
Sodium sulfate	9.0	7.0	8.5	–
Sodium silicate	4.0	–	–	–
Soluble glass 3:1[a]	10.0	11.0	9.5	7.0
Carboxymethylcellulose	1.0	2.0	2.0	2.0
Carbamide	–	7.0	–	–
Perborate	–	10.0	13.0	–

[a]Sodium silicate $(n)Na_2O(m)SiO_2$ with n = 1 and m = 3.

Both 5- and 10-g/L concentrations of washing agent were used. Washing time in one washing cycle was 15, 20 and 25 min. Hardness of the water used was 8.7, 12.0 and 20.0°n (i.e., degrees on the German hardness scale. 1°n = 0.3566 meq of Ca^{2+} in 1 L of H_2O). The experiments were conducted at temperatures of 40, 60 and 90 C.

The washings were performed in an LHD-EF launderometer. Optical measurements were made with an Opton-Elrepho leucometer.

Preparation of Washing Solutions

The washing solutions were prepared by dissolving weighed portions of washing agents in water of appropriate hardness. The washing agents were prepared according to previously described formulae.

Preparation of Water of Required Hardness

The water of required hardness was prepared by dissolving appropriate amounts of anhydrous calcium chloride $CaCl_2$ and hydrated magnesium sulfate $MgSO_4 \cdot 7H_2O$ in distilled water.

Preparation of Fabric Samples

The fabrics already described were cut weftwise into strips 6 cm wide. The strips were next cut warpwise into 12-cm-long pieces and marked with white thread.

Washing Process

Each piece of fabric was subjected to three subsequent washing cycles. A freshly prepared washing solution was used for each washing.

The washing process consisted of: (a) washing in a portion of solution of a given concentration and temperature for a predetermined period of time; (b) rinsing; (c) drying by pressing between sheets of blotting paper; (d) leucometric measurement.

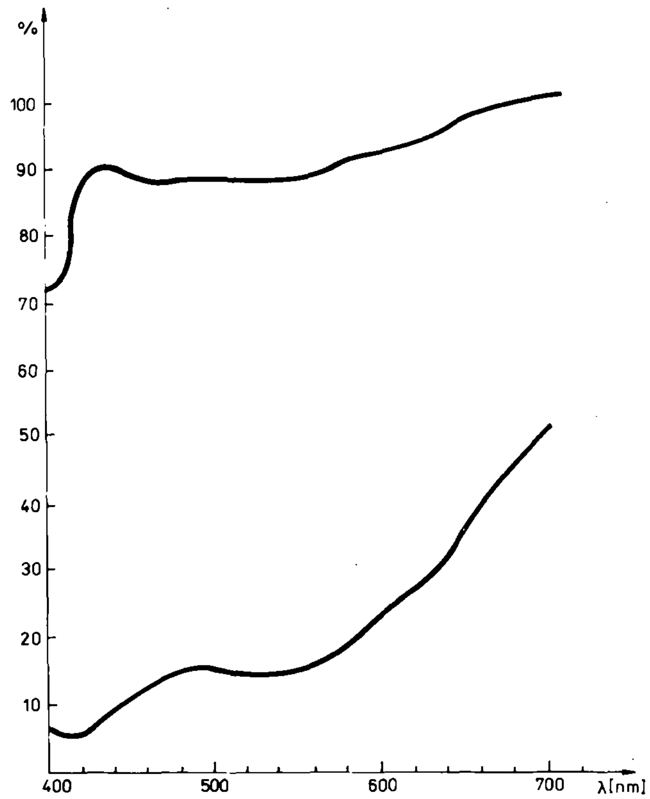

FIG. 2. Spectral distribution of an EMPA 111 test fabric: (1) white; (2) soiled.

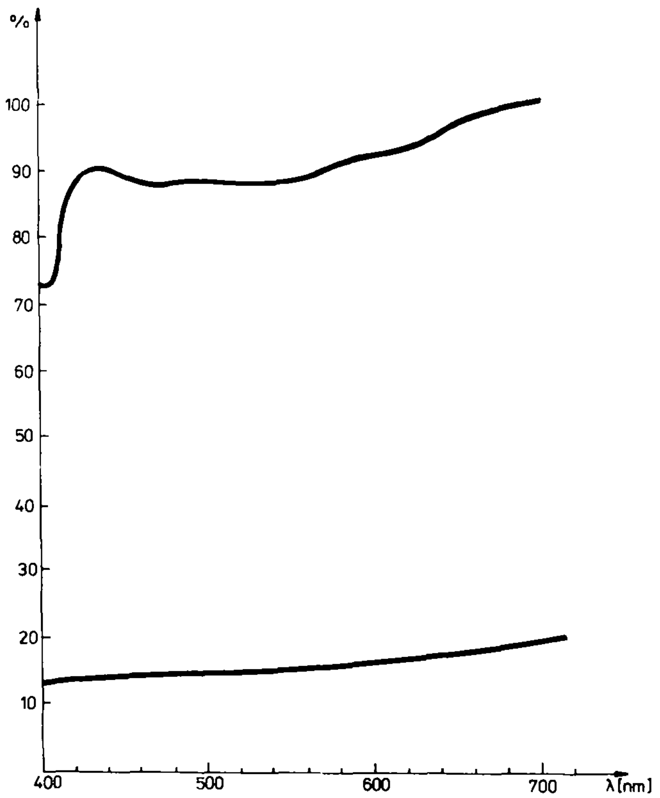

FIG. 1. Spectral distribution of an EMPA 101 test fabric: (1) white; (2) soiled.

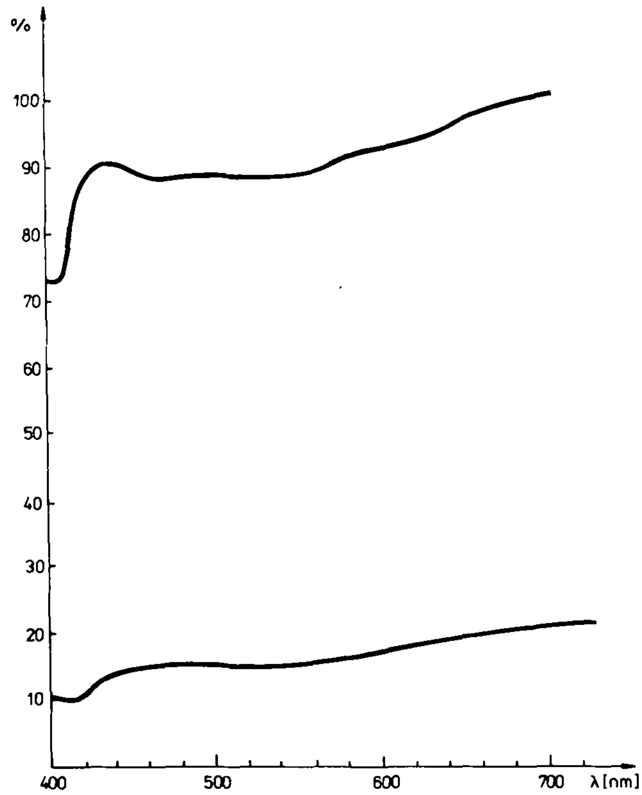

FIG. 3. Spectral distribution of an EMPA 116 test fabric: (1) white; (2) soiled.

TABLE I

Results of Estimating Washing Power[a]

Fabric		EMPA 101					EMPA 111					EMPA 116				
Temperature (C)	Washing agent	Mean degree of cleaning y	Mean degree of cleaning %	Washing power, C %	Standard deviation, S_c	Confidence interval, μ	Mean degree of cleaning y	Mean degree of cleaning %	Washing power, C %	Standard deviation, S_c	Confidence interval, μ	Mean degree of cleaning y	Mean degree of cleaning %	Washing power, C %	Standard deviation, S_c	Confidence interval, μ
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
40	A	y_1	60.0				y_1	69.5				y_1	53.1			
		y_2	67.5	70.1	0.66	1.40	y_2	75.3	78.4	0.68	1.44	y_2	56.0	57.1	0.54	1.14
		y_3	69.4				y_3	77.3				y_3	56.8			
	B	y_1	58.1				y_1	44.0				y_1	25.4			
		y_2	63.4	67.8	1.38	2.93	y_2	60.5	68.5	0.80	1.70	y_2	26.4	27.1	0.86	1.82
		y_3	65.8				y_3	65.9				y_3	26.8			
	C	y_1	62.4				y_1	47.9				y_1	21.8			
		y_2	68.9	69.7	0.38	0.81	y_2	67.9	73.1	1.12	2.37	y_2	23.1	25.2	3.32	7.04
		y_3	69.6				y_3	72.0				y_3	23.9			
	D	y_1	40.9				y_1	73.7				y_1	44.8			
		y_2	46.0	46.7	0.70	1.48	y_2	78.4	83.7	2.04	4.32	y_2	48.0	53.3	2.84	6.02
		y_3	46.2				y_3	80.9				y_3	50.0			
60	A	y_1	65.7				y_1	76.2				y_1	62.5			
		y_2	70.2	74.9	2.12	4.49	y_2	87.5	88.5	0.36	0.76	y_2	67.9	71.9	1.22	2.59
		y_3	72.5				y_3	88.4				y_3	70.9			
	B	y_1	67.8				y_1	73.5				y_1	32.3			
		y_2	72.1	77.5	1.36	2.88	y_2	76.0	76.2	0.36	0.76	y_2	34.7	36.7	1.12	2.37
		y_3	74.5				y_3	76.2				y_3	35.8			
	C	y_1	67.4				y_1	56.1				y_1	25.9			
		y_2	77.2	86.2	1.56	3.12	y_2	67.4	71.5	0.64	1.36	y_2	30.3	31.3	0.48	1.02
		y_3	81.9				y_3	70.4				y_3	31.1			
	D	y_1	60.6				y_1	70.7				y_1	49.4			
		y_2	68.0	74.3	1.42	3.01	y_2	80.8	85.9	0.84	1.78	y_2	52.0	52.5	0.44	0.93
		y_3	71.4				y_3	84.2				y_3	52.4			
90	A	y_1	70.1				y_1	71.3				y_1	53.2			
		y_2	77.2	83.4	1.46	3.10	y_2	79.6	83.0	0.70	1.48	y_2	65.2	76.1	1.44	3.05
		y_3	80.5				y_3	82.0				y_3	71.2			
	B	y_1	76.1				y_1	54.0				y_1	38.1			
		y_2	83.2	97.1	2.27	4.81	y_2	72.3	89.6	1.62	3.43	y_2	40.8	47.8	3.29	6.97
		y_3	87.9				y_3	81.2				y_3	42.7			
	C	y_1	67.5				y_1	67.2				y_1	24.4			
		y_2	79.6	88.1	1.14	2.42	y_2	73.5	76.6	0.82	1.74	y_2	28.0	36.2	5.74	12.17
		y_3	84.6				y_3	75.6				y_3	30.5			
	D	y_1	51.8				y_1	77.6				y_1	55.4			
		y_2	72.0	85.0	1.04	2.20	y_2	79.0	80.0	1.22	2.59	y_2	67.7	77.3	1.28	2.71
		y_3	79.9				y_3	79.6				y_3	79.1			

[a]Washing time, 20 min, washing agent concentration, 5 g/L, water hardness, 12°n.

In order to evaluate the washing power of any one washing agent, four samples of each fabric were subjected to three washing cycles each in a launderometer. One launderometer pot contained two samples, 10 steel balls and 100 mL of a washing solution of a given concentration. To avoid soil migration on the fabric and the formation of stains, the samples were quickly immersed in the washing solution.

After the washings, the samples were rinsed thoroughly three times in water of 40-45 C temp and once in water of 20-25 C. The hardness of the rinsewater was the same as that of the water used for the preparation of the washing solution.

After squeezing and wringing, the samples were spread between two sheets of blotting paper and pressed until dry with an iron adjusted to a temperature appropriate for cotton.

Leucometric Measurement

An Opton-Elrepho leucometer was used for the measurements. The integral intensity of scattered light is easiest to examine when the absorption spectrum of soil has wide bands that are uniformly distributed over the entire visible range. Such is the property of most common test soils. The spectral distributions of soiled samples were made on a UV-VIS Zeiss spectrophotometer Model VSU-2P. The spectral distributions for EMPA 101, 111 and 116 fabric samples are shown in Figures 1-3.

The relative intensity of scattered light was measured after calibrating the instrument. The widest range of intensity variations was obtained when the intensity of light scattered on the perfect radiator was assumed to be the lowest, and the intensity of light scattered on a white standard to be the highest.

In the first part of this work on evaluation of washing power (5), it was shown to be practical to compensate for the intensity of light reflected from the maximally soiled fabric. For that purpose, the intenstiy of light scattered on this fabric shall be assumed to be the lowest, and the intensity of light scattered on white, unsoiled fabric shall be considered the highest. The instrument adjusted this way permits a considerably wider measuring range and, in consequence, an increased measuring accuracy.

The leucometric measurements were made for the entire visible light range, 400-700 nm, obtained by removing any pair of filters.

Each sample was folded and measured four times, twice on each side. A 0-100% washing scale was determined before the measurements. A standard soiled, unwashed sample was considered 0% washed, and a control sample of each fabric was assumed to be 100% washed.

The degree of cleaning was measured for each sample after each of the three washing cycles.

RESULTS

The mean degree of cleaning was calculated for each fabric sample after each of three washing cycles. Sixteen leucometric measurements were obtained for each kind of fabric tested.

The washing power, C, of a given washing agent used to remove a given kind of soil was calculated from the equation:

$$C = \frac{y_1 y_3 - y_2^2}{y_1 + y_3 - 2y_2},$$

where y_1, y_2, y_3 = average (%) degree of cleaning of each sample after each of the three washing cycles.

In addition to the washing power C, the number of

TABLE II

Relation between Degree of Cleaning and Number of Washings[a]

Fabric / Washing agent	EMPA 101: Mean degree of cleaning, y	%	Washing power, C %	Standard deviation S_c	Confidence interval, μ	Calculated number of washings, x_g	EMPA 111: Mean degree of cleaning, y	%	Washing power, C %	Standard deviation, S_c	Confidence interval, μ	Calculated number of washings, x_g	EMPA 116: Mean degree of cleaning, y	%	Washing power, C %	Standard deviation, S_c	Confidence interval, μ	Calculated number of washings, x_g
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
C	y_1	66.2					y_1	58.9					y_1	31.6				
	y_2	74.5					y_2	68.4					y_2	34.5				
	y_3	77.7					y_3	72.9					y_3	35.8				
	y_4	78.5	79.7	0.82	1.74	5	y_4	74.3	76.9	1.52	3.22	6	y_4	36.0	36.9	1.36	2.88	5
	y_5	78.9					y_5	74.8					y_5	36.3				
	y_6	79.1					y_6	75.3					y_6	36.6				
	y_7	79.2					y_7	75.9					y_7	36.5				
A	y_1	66.3					y_1	78.1					y_1	59.1				
	y_2	70.9					y_2	83.2					y_2	65.4				
	y_3	73.1					y_3	85.3					y_3	67.0				
	y_4	74.3	75.1	1.56	3.31	6	y_4	85.5	86.8	1.14	2.42	5	y_4	67.0	67.5	0.60	1.27	3
	y_5	74.6					y_5	85.8					y_5	67.1				
	y_6	74.6					y_6	86.3					y_6	67.1				
	y_7	74.7					y_7	86.4					y_7	67.3				

[a]Washing agent concentration, 5 g/L, washing time, 20 min, working temp 60° C, water hardness 8.7°n.

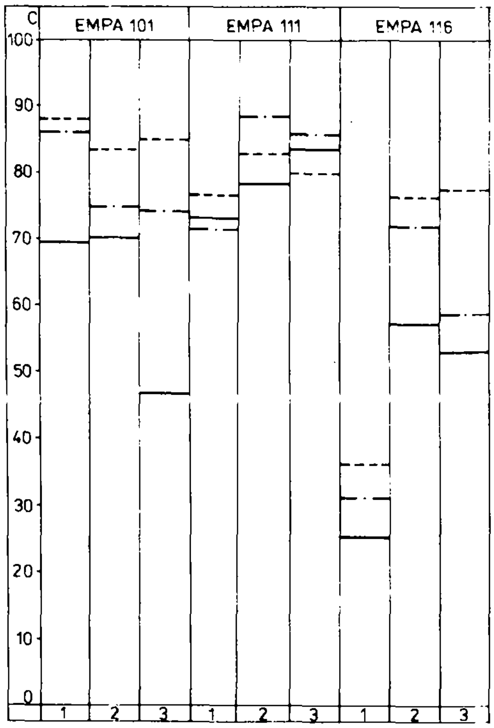

FIG. 4. Washing power C of investigated washing agents (washing agent concentration 5 g/L, washing time 20 min, water hardness 12°n).

washing cycles necessary to obtain the required degree of cleaning was also calculated. The required degree of cleaning differs by a ΔC value from a maximum degree of cleaning obtainable in given conditions with a given washing agent. The number of washing cycles was calculated from the equation:

$$x = \frac{\ln \frac{C}{\Delta C}}{\ln \frac{C-y_1}{C-y_p}}$$

where $\Delta C = 1\%$.

The method was then used to evaluate the washing power of chosen washing agents. Results are listed in Table I.

To check the results vs the theoretically calculated number of cycles necessary to obtain a C degree of cleaning, the relation between the degree of cleaning for a given kind of soil and the number of washing cycles was examined. The results obtained for two washing agents A and C are shown in Table II.

The washing power of three washing agents at various washing conditions is shown in Figure 4.

DISCUSSION

The experiments confirmed the correctness of the model described in part I of this paper (*JAOCS*, 58:1012). This suggests its potential for evaluation of the clearing power of various washing agents on cotton fabrics.

A close relation was found between the cleaning effect of a given agent and the soil type, washing temperature, one cycle's washing time, the washing agent concentration and water hardness.

Multiple washings of the same fabrics in fresh washing solutions allowed for maximal washing power characteristic of a given kind of soil, washing agent and fabric.

Besides the information on maximum achievable degree of cleaning, the method provides information on the dynamics of the soil removal process. This method of evaluating washing power is easy, economical, gives repeatable results and classifies the washing agents tested.

The results obtained are consistent with "washing-machine test" results. Classification of washing agents was the same for both kinds of tests.

The following conclusions based on the results obtained may be made: (a) the best results were obtained after a 20-min washing: (b) the temperature for determining washing power must be the same as the washing temperature denoted for a given washing agent: (c) the composition of chosen test soils (pigment/grease EMPA 101, blood-soiled EMPA 111 and pigment/grease/protein EMPA 116) was as close as possible to natural soil composition.

The described method of evaluating washing power allows for the optimization of washing agents.

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