A New Method for Evaluating the Washing Power of Washing Agents for Cotton Fabrics: I. Description

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ABSTRACT

This work describes a new method of evaluating washing effectiveness based on analysis of light scattering on washed fabric. A relationship was found for determining the maximal degree of cleaning achieved using given washing agents in given physicochemical conditions. The errors in the method for evaluating the degree of cleaning are also discussed in this work.

INTRODUCTION

The method of evaluating the effectiveness of washing agents is one of the most important aspects in testing their usefulness.

Evaluation of the degree of cleaning usually requires considerable data, acquired either by practical methods such as natural laundering performed in households, or under laboratory conditions (1-3). Up to now, most methods of evaluating the degree of cleaning were based on single washings of standard soiled fabric samples (4-6). Some authors (7) think, though, that the degree of cleaning cannot be objectively evaluated after a single washing of a given piece of fabric.

Certain physical parameters, such as the degree of light reflection (1-9) or the quantity of removed soil (10) are estimated after washing using various methods. A more specific chemical analysis of washing products (8) may be performed instead. Possibilities of improving the precision of this research arise with the introduction of better measuring equipment. These include, e.g., devices that transmit the results of optical measurements from a spectrometer directly to a computer (2).

Optical methods of evaluating the degree of cleaning used until now have differed greatly from each other. Such methods include the simple visual evaluation connected with a specially worked-out system of experiments (1,3, 11), comparison to chosen standards (4,12,13), more precise methods using leucometers or spectrometers (2-7,9, 13,14) and microscopic and photographic methods (15).

There are advantages and faults with each method. At present, it seems impossible to work out a method permitting an objective and explicit evaluation of the degree of cleaning, taking into account all parameters that influence results.

Visual evaluation, e.g., requires a large number of experiments and qualified staff for the evaluation of compared material.

The comparative method is usually applied to white fabrics. Such methods are aimed at making a fabric as white as possible vs a given standard, even though a clean fabric may have a different shade of white. Also, soil removal should not result in a change of color. The use of optical brighteners, e.g., bluing, is just a half-measure.

Results obtained with leucometers seem to be promising, since such methods provide for: (a) uniform illumination of the sample, (b) the possibility of performing refractional measurements using filters to take into account spectral composition of the examined light, and (c) the possibility of comparing the results to any standard, including the unsoiled and maximally soiled fabrics. The dilemma is to find a method relating the results of measurements of light reflection to the washing power of a given washing agent.

Many authors use the theoretically derived Kubelka-Munk equation (16), relating the coefficients of light absorption, K, reflection, R, and scattering, S, as:

$$\frac{K}{S} = \frac{1 - R^2}{2R}$$

Some authors have tried to use this formula to determine washing power assuming that the K/S ratio is linearly dependent on the soil layer thickness. Lambert and Sanders (17), as well as other authors, proved this assumption untrue. Moreover, the widely used washing power equation:

$$D = \frac{R_a - R_b}{R_c - R_b} \times 100,$$

where: R_a = coefficient of light reflection from a washed fabric; R_b = the coefficient of light reflection from a soiled fabric; and R_c = the coefficient of light reflection from a clean fabric, in most cases does not show a linear relation between D and R_a when R_b and R_c are constant. In many cases, the results obtained using this method are not diverse enough to determine which washing agent was better.

The purpose of our work was to develop a method permitting a possibly fast, economic and objective evaluation of the degree of cleaning.

Definition and Method of Determining Washing Power

Let us examine more closely the processes of soiling and washing the fabric. To achieve this, let us assume the simplest model possible and compare the results obtained for this model with the results of the experiment.

Let us assume that soiling means the application of a layer l upon a white base p (100% reflection of light for every wavelength in the visible spectral range). The layer l partly reflects and partly absorbs the light of I_0 intensity (Fig. 1). The intensity of light reflected from such a layer:

$$I = I_1 + I_2,$$

will include a constant factor I_1 and a factor I_2 that are dependent on the thickness l of the applied layer.

Let us examine the last relation more closely. The intensity I_2 decreases after passing through layer dl (Fig. 2). It is usually assumed that the number of quanta absorbed by the layer dI_2 is proportional to the layer's thickness dl and to the intensity of light I_2. Then:

$$dI_2 = -kI_2 dl,$$

and:

$$\frac{dI_2}{I_2} = -kdl \Longrightarrow \ln I_2 = -kl + \ln a,$$

where a = integration constant:

$$\ln \frac{I_a}{a} = -kl \Longrightarrow I_2 = a\cdot e^{-kl}$$

The integration constant can be easily determined from boundary conditions if we note that for $l = O$, $I_2 = I_{2o}$, so that $I_2 = I_{2o}{\cdot}e^{-kl}$. The overall intensity of light reflected from such a layer is expressed by the equation:

$$I = I_{2o}{\cdot}e^{-kl} + I_{1o} \qquad [I]$$

This function is plotted in Figure 3. Note that, if the layer thickness increases linearly, the information obtained by measuring the reflected light intensity I is an exponential function (Equation I). The plot of this relation is even simpler if the measuring device compensates for the intensity of reflected light I_{1o}:

$$I = I_{2o}{\cdot}e^{-kl}$$

Compensation may be accomplished by substituting a complete radiator with a maximally soiled fabric sample. (Maximally soiled fabric has a soil layer of thickness $l \geq l_g$, where l_g is the thickness completely sufficient for absorption of penetrating light I_2. For practical purposes, one can assume that it is a layer of such thickness, that optical density A = 3.0.) In this case, if the layer thickness is increased linearly, the obtained I (in Equation I) function will be similar to that shown in Figure 4-curve 1.

If the soil layer is removed, the relation between light intensity and layer thickness is obvious:

$$I = I_{2o} - I_2 e^{-kl'} = I_{2o}(1 - e^{-kl'}), \qquad [II]$$

i.e., curve 2 in Figure 4, where: l' = the thickness of layer removed from the base.

If it assumed that the layer thickness l' variations are proportional to the number of washings x ($l' = nx$), then:

$$I = I_{2o}(1 - e^{-knx}) = I_{2o}(1 - e^{-bx})$$

It is convenient now to introduce a function:

$$y = \frac{I}{I_{2o}} \cdot 100\%,$$

so that:

$$y(x) = (1 - e^{-bx})\ 100\% \qquad [III]$$

The process of washing in a cleaning solution is complex. It is possible to distinguish some stages in this, such as the separation of a soil layer from a lower soil layer or the separation of a soil layer from the base—the cloth fibers. The mechanisms of each stage differ, depending on the choice of washing agent, the kind of fabric and the kind of soil.

If a layer of soil l_o is left after a repeated number of washings, Equation I may be rewritten as (curve 4, Fig. 4):

$$I = I_{2o}{\cdot}e^{-k(l_o + 1)} = I_{2o}{\cdot}e^{-kl_o}e^{-kl}, \qquad [IV]$$

so that:

$$I = I_{2o}{\cdot}C{\cdot}e^{-kl},$$

where:

$$C = e^{-kl} < 1$$

Similar to the case of removing the soil, the following relation is derived:

$$I = I_{2o}{\cdot}C(1 - e^{-kl'}) \qquad [V]$$

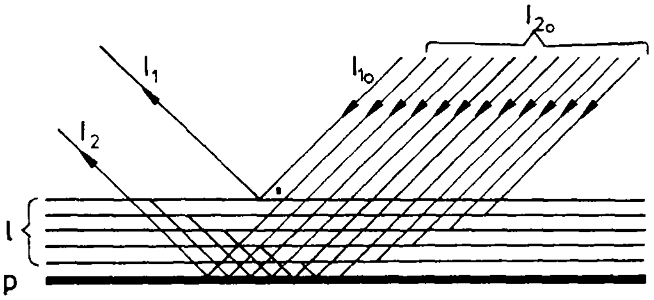

FIG. 1. Partial reflection and absorption of the light by the soil layer l and base p.

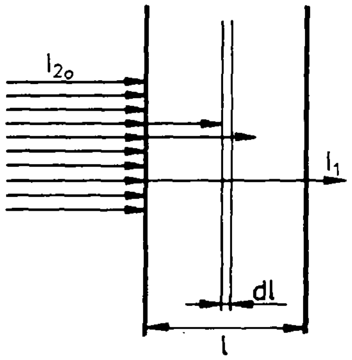

FIG. 2. The absorption of light by the soil layer according to the Lambert-Beer rule.

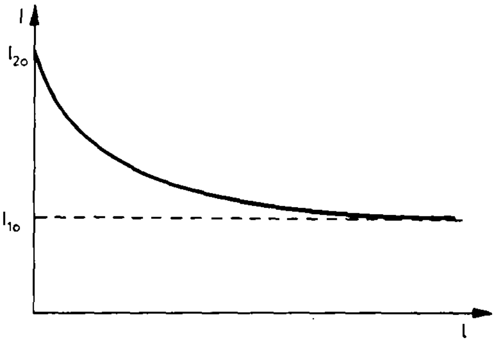

FIG. 3. The dependence of the intensity of the absorbed light on the thickness of the soil layer.

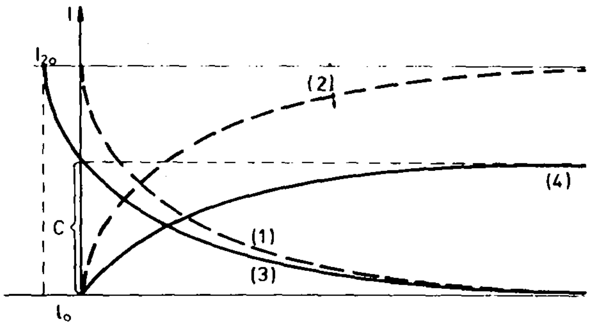

FIG. 4. The dependence of the intensity of the light for: (1) the thickness l of the layer-deposited soil; (2) the thickness l' of soil layer removed from the base; (3) the thickness of elementary soil layer l_o; (4) the thickness of soil layer l' removed from the base with elementary layer l_o left on.

Or, if a number of washings is introduced:

$$I = I_{2_0}C(1 - e^{-bx}),$$

so that:

$$y(x) = \frac{I}{I_{2_0}} \cdot 100\% = C(1 - e^{-cx}) \qquad [VI]$$

This function is plotted as curve 3 in Figure 4.

The value $C = e^{-\frac{bl}{n}} \cdot 100\%$ (the asymptote of y(x) function) as well as b characterize the washing power of a tested washing agent. Value C determines the degree of cleaning possible to achieve with a given agent. Value b shows the number of washings necessary to achieve that degree of cleaning. The rate of the y(x) function variations is dependent on value b.

The thickness of the soil layer is equivalent to the superficial soil concentration.

The soil layer thickness was introduced to increase the demonstrativeness of the assumed model. The course of the analyzed phenomena would not be altered, though, if a superficial soil concentration was introduced instead.

DISCUSSION

We will now speculate on how to determine the tested values. Constant C is easy to determine after performing three subsequent washings, when values y_1, y_2 and y_3 are obtained:

$$\left.\begin{array}{lll} y_1 = C - Ce^{-b} & C - y_1 = Ce^{-b} & (a) \\ y_2 = C - Ce^{-2b} & C - y_2 = Ce^{-2b} & (b) \\ y_3 = C - Ce^{-3b} & C - y_3 = Ce^{-3b} & (c) \end{array}\right\} \qquad [VII]$$

Dividing Equation VIIb by VIIa and VIIc by VIIb we have:

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

and, in consequence:

$$C = \frac{y_1 y_3 - y_2^2}{y_1 + y_3 - y_2} \qquad [VIII]$$

Constant b is obtained by differentiating Equation VI:

$$\frac{dy}{dx} = Cbe^{-bx}$$

If it is possible to determine this derivative for x = 0 (the inclination angle tangent of a tangent to a curve y(x) at the zero point of the coordinate system), then:

$$b = \frac{\left.\frac{dy}{dx}\right|_{x=0}}{C}$$

The previous definition of b is invalid if the initial layer is thicker than l_g. The best solution, then, is to calculate b from Equation VII. After taking a logarithm and transforming Equations VIIa,b,c, the following relations are obtained:

$$b = \ln\frac{C - y_1}{C - y_2} = \ln\frac{C - y_2}{C - y_3} \ldots \text{etc.} \qquad [IX]$$

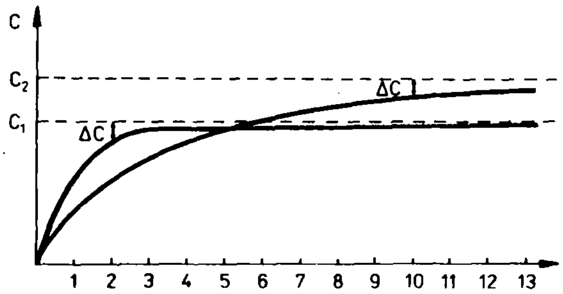

FIG. 5. The dependence of y function on the number of washings for different kinds of washing agents.

Constant b could be of significant value where C values are widely different, but it is necessary to perform a considerably larger number of washings to obtain $C_2 > C_1$ (Fig. 5). This figure shows that the expected result is obtained after 10 washings when a washing agent of a C_2 washing power is used. The degree of cleaning differs from a maximal degree of cleaning by ΔC. The use of a washing agent with a C_1 washing power permits the acquisition of the expected degree of cleaning after only 2 washings. If the number of washings does not exceed 7, the use of a washing agent with a C_1 washing power results in a better degree of cleaning. In consequence, the degree of cleaning can be characterized by an additional parameter (excluding C) instead of b. The number of washings necessary to obtain a degree of cleaning differing by ΔC from a maximal degree of cleaning achieved with a given washing agent could be used as such a parameter. The transformation of Equation VI results in:

$$C - y_g = \Delta C = Ce^{-bx_g},$$

so that:

$$x_g = \frac{1}{b}\ln\frac{C}{\Delta C} \Longrightarrow \frac{\ln\frac{C}{\Delta C}}{\ln\frac{C - y_1}{C - y_2}},$$

where x_g is the number of washings necessary to satisfy the above condition.

The rate (number of washings) to achieve the expected degree of cleaning may be calculated in a similar fashion.

Errors of the Method of Evaluating Degree of Cleaning

The errors arising from the determination of y_1, y_2, y_3 values are transmitted to the C value. If the Δy errors are considered small, an approximation with a Taylor's series limited to linear expansion terms may be used:

$$\Delta C = \frac{\delta C}{\delta y_1}\Delta y_1 + \frac{\delta C}{\delta y_2}\Delta y_2 + \frac{\delta C}{\delta y_3}\Delta y_3$$

Assuming Δy_1, Δy_2 and Δy_3 as uncorrelated random variables with identical variances and normal distribution (a reasonable assumption, since y is calculated as a mean value from a large number of leucometric measurements), the following C variance is obtained:

$$S_C^2 = \left[\left(\frac{\delta C}{\delta y_1}\right)^2 + \left(\frac{\delta C}{\delta y_2}\right)^2 + \left(\frac{\delta C}{\delta y_3}\right)^2\right] S_y^2$$

If an electronic calculator is used, the following form of practical derivatives is convenient:

$$\frac{\delta C}{\delta y_1} = \left(\frac{1}{1 + \frac{y_1 - y_3}{y_3 - y_2}}\right)^2$$

$$\frac{\delta C}{\delta y_2} = \frac{2}{\left(1 + \frac{y_1 - y_2}{y_3 - y_2}\right)\left(1 + \frac{y_3 - y_2}{y_1 - y_2}\right)}$$

$$\frac{\delta C}{\delta y_3} = \left(\frac{1}{1 + \frac{y_3 - y_2}{y_1 - y_2}}\right)^2$$

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,

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

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,