TABLE VI

Composition of Total Fatty Acids

Analytical method	Fractionation, %	Thiocyanometric, %	Thiocyanometric, %
Cassia fistula			
Origin	India	India	Africa(5)
Oleic	30.70	34.23	31.90
Linoleic	48.09	46.90	39.00
Palmitic	16.01	18.87	29.10
Lignoceric	5.20		
Cassia occidentalis			St. Martins
Origin	India	India	(17)
Oleic	.....	31.60	34.80
Linoleic	.....	38.10	35.70
Linolenic	.....	6.30	7.10
Palmitic	19.68	24.00[a]	22.40
Lignoceric	4.32		
Cassia tora			
Origin	India	India	India(14)
Oleic	28.12	27.20	.....
Linoleic	45.02	45.20	.....
Palmitic	23.43	27.60	.....
Lignoceric	3.43		

[a] Bertram (2).

small quantities of resins. The data on fatty acid compositions determined in the present study compare well with the data previously reported (Table VI) and show that these oils differ from other seed oils in containing lignoceric acid (1, 16, 14) but little (1) or no stearic acid (16, 14).

Cassia oils contain about the same proportion of linoleic acid as do soybean and linseed oils. It was observed that there is more linoleic acid and a smaller amount of saturated acids in the Indian than in the African varieties of *Cassia fistula* oils. Although the oil content of the Indian variety of *C. occidentalis* seed is slightly higher than that of the St. Martins Island variety, the properties of the oils are the same.

The oil from *C. tora* which contains chrysophanic acid may find use as a purgative or intestinal disinfectant. The soap may be useful in the treatment of skin diseases, such as ringworm and itches.

Summary

Fatty acids from oils of Indian varieties of *C. fistula, C. occidentalis,* and *C. tora* were fractionated by the lead salt-alcohol and methyl ester distillation methods. Compositions were calculated from the iodine values and saponification equivalents of the ester fractions. Identities of saturated acids were established by determining the properties of the recrystallized acids. Unsaturated acids were identified as the bromo- and hydroxy-derivatives.

Cassia fistula, C. occidentalis, and *C. tora* oils were found to contain the following percentages of fatty acids, respectively: palmitic, 16.0, 19.7, 23.5; lignoceric, 5.2, 4.3, 3.4; oleic, 30.7, 31.6, 28.1; and linoleic, 48.1, 38.1, 45.0. In addition, *C. occidentalis* oil contained 6.3% of linolenic acid.

Chrysophanic acid was isolated in yield of 0.6% from *C. tora* oil, but only traces were obtained from *C. occidentalis* oil.

Acknowledgment

The authors acknowledge their indebtedness to a grant-in-aid placed at their disposal by the Indian Central Oilseeds Committee for this investigation.

REFERENCES

1. Ahmad, Z., Z. Untersuch. Lebensm., *70*, 166 (1935).
2. Bertram, S. H., "Vegetable Fats and Oils," by Jamieson, 2nd ed., p. 414, New York, Reinhold Publishing Corporation, 1943.
3. Baughman, W. F., and Jamieson, G. S., J. Am. Chem. Soc., *42*, 152 (1920).
4. Elborne, Pharm. J., 242, September 22, 1888.
5. Grindley, D. N., J. Soc. Chem. Ind., *65*, 118–19 (1946).
6. Hilditch, T. P., "The Chemical Constitution of Natural Fats," 2nd ed., p. 468, London, Chapman and Hall Ltd., 1949.
7. Hilditch, T. P., *ibid.*, p. 474.
8. Hilditch, T. P., *ibid.*, p. 505–6.
9. Hilditch, T. P., *ibid.*, p. 464.
10. Hilditch, T. P., *ibid.*, p. 509.
11. Lewkowitsch, J. S., "Chem. Tech. and Analysis of Oils, Fats and Waxes," 6th ed., vol. 1, p. 636, London, Macmillan and Company Ltd., 1921.
12. Lewkowitsch, J. S., *ibid.*, p. 574.
13. Lewkowitsch, J. S., *ibid.*, p. 588.
14. Manjunath, B. L., and Jois, H. S., J. Indian Chem. Soc., *7*, 521–26 (1930).
15. Method of Analysis of Fats and Oils, British Standard, 684, p. 41, 1950.
16. Singh, B. K., and Tewari, R. D., Proc. Natl. Acad. Sci. India, 111–19 (1943).
17. Steger and van Loon, Rec. trav. chim. *53*, 28 (1934).
18. Vogel, I. A., "Practical Organic Chemistry," 1st ed., p. 111, London, Longman, Green and Company, 1948.

[Received June 4, 1954]

Preliminary Report on a Rapid Method of Evaluating Detergency by Means of an Ultrasonic Transducer

JOSEPH C. SHERRILL, College of Household Arts and Sciences, Texas State College for Women, and W. CRAIG WHITE, Chemicals and Plastics Division, Quartermaster Research and Development Center, Natick, Massachusetts

THERE HAS BEEN a serious need for a highly objective but rapid method for obtaining comparative detergency data on compounds and procedures so that these could be evaluated with a high degree of accuracy and precision.

It is believed that this need is being met as a result of the work described in this report. An ultrasonic transducer, designed and built by Clevite-Brush Company, Cleveland, Ohio, has been adapted in the laboratories of the first-named author to the purpose of removing soil from standard soiled surfaces in a short period of time, under circumstances in which the actual energy output of the transducer is known. This energy output can be related to the amount of soil removed from an exposed surface.

The ultrasonic transducer, with the adaptations as applied in converting the original device to the purpose in hand is suitable for determining the removal of soil on a quantitative basis from the following types of surfaces: a) various textiles, b) metallic surfaces, c) ceramics, and d) plastics.

Experimental Procedure

The Cone Transducer. Work has been directed in these laboratories toward the investigation of sound transducers of several types. The development most applicable to this study was found to be the cone transducer, after examination of the operational characteristics of four other transducer types. Investigations into the magnitude of energy required

to remove soils from surfaces require a device for providing mechanical action of a very measurable and reproducible type. Accordingly it was decided to use the cone transducer as a means of obtaining measurable mechanical action which could be related to soil removal. The instrument used in these studies consists of a truncated brass cone, having a base diameter of 1 in. and a diameter at the tip of $\frac{1}{16}$-in. Excitation is provided by means of a 0.27-in.-thick barium titanate disc attached to the base by means of a special lead-tin-silver solder. The ceramic element is operated far below its resonant frequency so that the modes of vibration in this transducer are controlled predominately by the cone itself. The cone is bolted in a tubular holder which has virtually no damping action on the cone.

An electronic generator with a self-contained automatic frequency control serves to drive the cone. This device, working in conjunction with a volt-ampere-watt meter, permits regulation and measurement of power input to the cone. The cone is driven at 45.8 kilocycles per second. It operates at maximum input of about eight to nine watts.

Measurements of Amplitude of Motion of Cone Transducer. An exhaustive series of measurements of a calibrational nature have been made on the cone transducer in order to determine the amplitude of vibration at the tip of the cone. It was necessary to determine amplitude in order to estimate the power output of the cone.

The acoustic power of a sound wave generated by a small piston can be computed from the following expression:

$$P = \varrho \frac{ck^2 S^2 (\omega A)^2}{4\pi} \times 10^{-7} \qquad (1)$$

where

P = average power, watts
ϱ = density of medium, gm./cm.^{3}
c = velocity of sound in medium, cm./sec.
k = ω/c
$\omega = 2\pi f$
f = frequency, sec.$^{-1}$
S = radiating area of piston, cm.^{2}
A = particle displacement amplitude, cm.

The first step in this work was the measurement of A, above, or the mean particle displacement amplitude at the tip of the cone. Measurements at the tip are pertinent since it is at this point that mechanical energy is transferred to the work area, that is to say, to the surface where cleaning is to be effectuated.

The measurement of A makes the equation listed above solvable for power output. Obviously the power output for any finite length of time reveals the total energy output available in the work area.

Amplitude measurements were made on the cone transducer by means of a microscope fitted with a calibrated eyepiece. A Bausch and Lomb Model FL-22 microscope having a 10 x eyepiece fitted with a micrometer was employed. A 16-mm. objective having a numerical aperature (n.a.) of 25 also was employed. This was calibrated by means of a microscope stage micrometer.

Calibration of the eyepiece indicated that 13 scale divisions represented 0.1 mm. Under these circumstances one scale division was equivalent to 7.7 microns.

TABLE I

Summary of Determinations of Mean Particle Displacement Amplitude of Brass Cone Transducer

Input Power, Watts	Number of Individual Determinations	Spot Length at Rest (l), Microns	Amplitude 1/2 (L—l), Microns
8	2	38	10.6
8	2	32	12.1
7.8	1	16	10.1
7.5	2	16	10.1
7	2	38	10.6
7	4	32	10.9
7	8	16	10.1
7	8	8	10.6
6.8	1	16	10.1
6	2	38	9.2
6	2	32	11.1
5	2	38	8.7
5	4	32	8.0
5	8	16	7.7
5	8	8	8.5
4	2	38	7.7
4	2	32	8.7
3.5	2	16	6.8
3	2	38	6.3
3	3	32	6.8
3	6	16	5.8
3	6	8	6.5
2	2	38	4.9
2	2	32	5.3
1	2	38	3.4
1	2	32	4.4

Considerable manipulation and repeated trials under a variety of conditions indicated that the measurement of the increase in area of a well-defined bright spot produced by sidelighting the surface of the cone would produce the most reliable estimates of amplitude of motion.

The amplitude of particle displacement was estimated by observing through a calibrated eyepiece the increase along the principal axis of the cone of the length of a bright spot. Geometric considerations lead to an expression for the mean particle displacement amplitude, namely:

$$A = \frac{L - l}{2} \qquad (2)$$

in which

A = mean particle displacement and amplitude, cm.
L = length of bright spot with cone energized, cm.
l = length of bright spot with cone at rest, cm.

In the course of the work bright spots produced by the sidelighting of various lengths were selected for making measurements. The length of these bright spots measured parallel with the direction of the principal axis of the cone varied from eight to 38 microns. A total of 87 individual observations of the particle displacement amplitude was recorded at points within approximately 100 microns from the tip of the cone. These observations are listed in Table I. Observations of the particle displacement amplitude at points approximately $\frac{1}{2}$ and $1\frac{3}{8}$ in., respectively, from the tip of the cone also were made. Observations of the particle displacement amplitude within 100 microns of the tip were made with the tip submerged in distilled water. The results under the conditions stated above are summarized in Table II.

In order to attach the proper degree of reliability to the figures recorded, eight determinations of particle displacement amplitude 1/2 (L — l) were made with bright spots having a length along the principal axis of the cone of about eight microns. The measurements were made at input power levels of seven,

TABLE II

Summary of Determinations of Mean Particle Displacement Amplitude at Various Points Along Cone Transducer

Input Power, Watts	Number of Individual Determinations	Spot Length at Rest (l), Microns	Amplitude 1/2 (L—l), Microns
At Tip of Cone (in Distilled Water)			
7	1	25	10.8
6	1	25	9.8
5	1	25	8.9
4	1	25	8.1
3	1	25	6.9
2	1	25	5.0
1	1	25	3.9
One-Half Inch From Tip (in Air)			
7	4	15	7.7
6	1	15	6.8
5	5	15	5.8
3	5	15	4.1
One and Three-Eighth Inches From Tip (in Air)			
8	1	35	2.9
6	1	35	1.9
4	1	35	1.0
2	1	35	0.0

five, and three watts. Statistical treatment of the results produced the following information:

Input Power, Watts	Number of Determinations	Particle Displacement Amplitude			Deviation	
		High	Low	Mean	Average $\bar{x}$	Standard σ
7	8	10.8	9.6	10.7	0.4	0.5
5	8	9.6	8.1	8.5	0.4	0.6
3	6	7.3	5.4	6.5	0.6	0.8

Considering the nature of the measurements, the results are remarkably reproducible. From the foregoing data the relationship between the amplitude and power input is a linear function.

The data previously derived can be used to estimate the power output of the cone transducer, the particle displacement amplitude being the only unknown factor.

The equation for acoustical power given previously is:

$$P = \varrho \frac{ck^2 S^2 (\omega A)^2}{4\pi} \times 10^{-7} \quad \text{watts} \qquad (1)$$

The following values appertain for the cone in air and in distilled water at 25°C.(77°F.).

	Air	Water
ϱ, gm./cm.^{3}	1.18×10^{-3}	9.97×10^{-1}
c, cm./sec.	3.47×10^{4}	1.50×10^{5}
k, $2\pi f/c$, cm.$^{-1}$	8.29	1.91
ω, $2\pi f$, sec.$^{-1}$	2.87×10^{5}	2.87×10^{5}
S, cm.^{2}	1.97×10^{-2}	1.97×10^{-2}
A, cm.	$A \times 10^{-8}$	$A \times 10^{-8}$
P, watts	$7.16 \times 10^{-6} A^2$	$1.39 \times 10^{-3} A^2$

Substitution of the value A, the mean particle displacement amplitude, in microns in equation (1) yields the following:

Input Power, Watts	Displacement Amplitude, Microns	Output Power, Watts at 25°C.(77°F.)	
		Air	Water
7	10.7	0.81×10^{-3}	1.58×10^{-1}
5	8.5	0.52×10^{-3}	1.00×10^{-1}
3	6.5	0.30×10^{-3}	0.59×10^{-1}

It is interesting to note that, for an input of seven watts to the cone, an output of 0.0008 watt is obtained in air. This is an efficiency of conversion of electrical to acoustic energy of about 0.012%. For an input wattage of seven the output in distilled water is about 0.158 watt, equivalent to a conversion of about 2%.

Obviously the energy output would be expressed as the product of the power output and the time period over which the cone is operated.

A Dynamic Detergency Tester

As has been set forth in preceding paragraphs, the quantity of energy expended by the cone transducer over any given time-interval has been determined. It then became necessary to develop a method for sweeping the cone over a soil surface in such a way that the brightness regain of this surface could be determined for any given value of energy expended.

The first type of surface considered for testing was that of a soiled textile fabric. It was conceived that an area of the fabric could be exposed to the energy output of the cone transducer by means of a turntable which would support a container into which is placed the standard soiled textile swatch submerged in a detergent solution. The cone could be suspended above the soiled test swatch, the vertical (principal) axis of the cone being perpendicular to its plane. The cone also could be moved across the face of the test swatch while the turntable would rotate. The combined motion of the fabric on the turntable would result in lineal travel of the tip of the cone from the center toward the outside of the swatch, exposing a circular area on the swatch to the mechanical action provided by the cone transducer. This circular area then would be examined in a Hunter Reflectometer or other type of reflectance device for overall soil removal.

Figure 1 embodies a simplified sketch of the dynamic detergency tester as conceived and assembled.

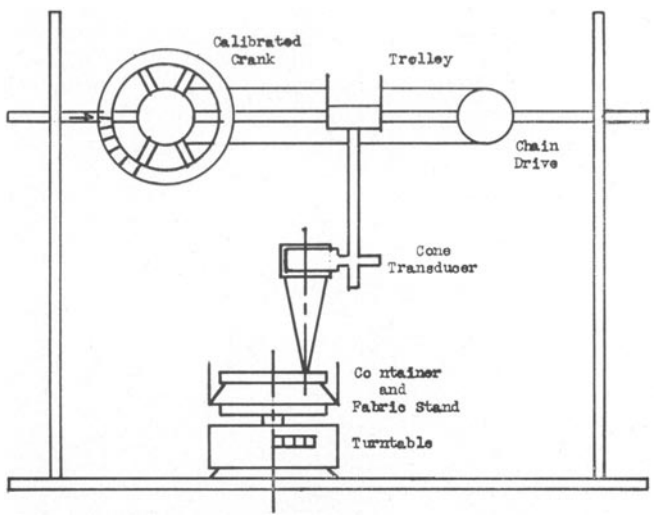

FIG. 1. Schematic diagram of dynamic detergency tester.

The test fabric is mounted onto a brass ring approximately 5½ in. in diameter and held in place by means of a rubber ring. In order to assure levelness of the swatch over the entire surface, a section of foam rubber was placed on a copper screen brazed to the under surface of the brass ring. The fabric drawn across the upper face of the bronze ring is supported by the foam rubber, and even loading across the entire path of the cone transducer is afforded.

The brass ring has three supports (legs) which fit snugly into a metal container having sides approximately 4 in. high and an inside diameter of 5½ in. The container holds 850 ml. of detergency solution.

A special platform designed to accommodate the container aforementioned has been constructed for use with a turntable. The turntable is driven electrically and revolves at a speed of 69.2 revolutions per minute.

The cone is supported by means of clamps on a trolley mounted over the turntable. The cone is clamped to a carriage which is moved back and forth on an overhead trolley. Transverse movement of the cone assembly is accomplished by turning the calibrated hand crank shown in Figure 1. The wheel is divided equally into 56 portions. Movement by one scale division of the wheel results in a lateral motion of the cone assembly of $\frac{1}{32}$ in. Following is the procedure used.

The cone assembly is set at the center of the swatch and levelled. The cone then is energized, and, with the turntable revolving, the cone is moved laterally from the center point of the container toward the periphery. As the cone is moved from the center of the container toward the periphery, it sweeps out concentric circles of soil much in the same manner as a block of wood is hollowed out by a cutting chisel mounted in a turret lathe. In this way a circular area of fabric is cleaned by the action of the cone transducer. Compressed air admitted through a glass spigot is played into the solution at the tip of the cone so as to minimize redeposition of soil, in the absence of the potentiality of adequate detergent to suspend the amount of removed soil in the relatively small amount of liquid present.

The swatch is shown schematically in Figure 2. The inner circle (OA), having a diameter of 3.38 in., corresponds to the area cleaned by the action of the cone transducer. The circle (OB) is that area supported by the foam rubber pad. The annulus BC is the thickness of the brass ring supporting the swatch. Arrow 1 shows the direction of travel of the swatch (turntable), and arrow 2 the path taken by the cone.

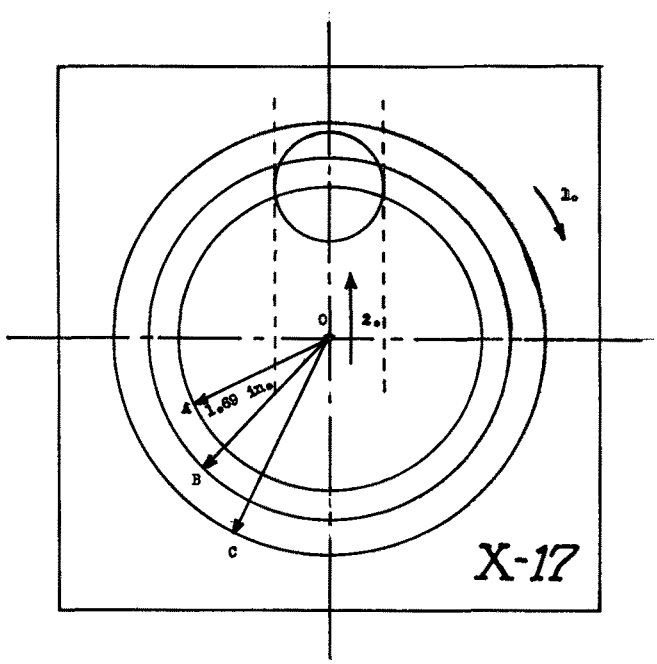

FIG. 2. Schematic representation of area of standard soil swatch subjected to cleaning action of cone transducer.

The problem in this instance is one in which the soil removal or brightness regain is to be related to the specific energy expended. The energy expended by the cone transducer obviously is the product of the power output and the time of contact.

It is of particular importance that the fabric area being cleaned be exposed evenly to the energy source. Thus every differential unit of area over the entire swatch should receive the same quantity of mechanical action. In the development of this procedure the following points have been considered.

The turntable is revolving at a constant rate of speed, namely 69.2 r.p.m. At any point along the path of the tip of the cone, the lineal travel of the point of the cone is

$$S = 2\pi r \qquad (3)$$

where

S = lineal travel, inches
r = distance between the center point O and the cone tip, inches

Since the time allotted for each revolution is the same regardless of the value of r in the above expression, obviously the time of contact between fabric and cone tip decreases as r increases. This results in greater overall time of contact between energy source and soiled surface at the center of the cleaned area unless provision is made to vary the time of exposure with variation in r.

In order to obviate this variation the following scheme has been devised. The cone is moved from the center to the periphery of the test piece in a series of discreet steps of $\frac{1}{32}$ in. Although the tip diameter of the cone is $\frac{1}{16}$ in., $\frac{1}{32}$-in. paths were chosen. Reasons for this are that the lack of a sharp shoulder at the edge of the cone tip results in diffusion of mechanical energy at and near the edge, giving rise to dark boundary rings between paths. Accordingly the steps in the path of the cone tip were set at $\frac{1}{32}$ in.; dark rings no longer appeared on the fabric surface.

Consider now the length of a circular path at a point $\frac{1}{32}$ in. from the center of the swatch. The length of the path, which is in fact the circumference of the circle, is:

$$\pi \times \text{diameter} = 3.14 \times \tfrac{1}{16} = 0.196 \text{ in.}$$

If the turntable revolves at a speed of 69.2 r.p.m., one revolution will require 60/69.2 or 0.867 seconds. The lineal rate of travel of the tip of the cone transducer at a point $\frac{1}{32}$ in. from the center of the swatch is obviously the lineal travel per unit of time or

$$\text{Rate} = 0.196/0.867 = 0.227 \text{ inches/second}$$

The reciprocal of rate is in this instance the time required for the cone tip to traverse a unit distance along the designated (circular) path. This value is

$$1/0.227 = 4.4 \text{ seconds/inch}$$

It may be deduced that, if 4.4 seconds are required for the tip of the cone transducer to traverse a distance of one inch at a path $\frac{1}{32}$ in. from the center, and 2.2 seconds are required to traverse the same distance at a point $\frac{2}{32}$ in. from the center, the inner path receives obviously twice as much energy output from the cone transducer as the outer path. In order to equalize exposure it is seen that, if one revolution of the turntable is employed at a path $\frac{1}{32}$ in. from the swatch center, two revolutions should be employed in the path 2/32 in. from the center, three

revolutions at the path $\frac{3}{32}$ in. from the center, and so forth. This system would result in an even energy distribution over the entire area subjected to the energy output of the cone transducer.

In actual practice 54 paths, each $\frac{1}{32}$ in. apart, are utlized in the technique under description. This produces a circular cleaned area of 54/32 or 1.69 in. radius, sufficiently large for evaluations in the Hunter Reflectometer or in other reflectance measuring devices. On the basis of one revolution for the innermost path ($\frac{1}{32}$ in.), two for the next ($\frac{2}{32}$ in.), three for the next, and so forth for 54 paths each $\frac{1}{32}$ in. apart, 1,485 revolutions would be required for each test run. This would be equivalent to a total exposure time of about 21.5 min. for each swatch.

The degree of brightness regain depends upon the amount of energy expended by the source in the work area, other factors being equal. The total quantity of energy required to produce brightness regain of sufficient magnitude to delineate the effects of all of the process variables in play in a detergency process were unknown at the outset. Preliminary runs indicated that a total contact time of about 10 min. spread over a circular area approximately 3 in. in diameter, produced soil removal in an area sufficiently large for the studies contemplated.

Accordingly the number of revolutions of the turntable at each path in the test procedure was treated by the factor 10/21.5.

Application of this factor results in a test period of 650 revolutions of the turntable. At a turntable speed of 69.2 r.p.m. this is equivalent to a total time of 563 seconds (9.39 min.). At a power input of seven watts the cone transducer produces 0.158 watt power. Each swatch therefore is subjected to $0.158 \times 563 = 89$ watt-seconds (joules) of mechanical energy, distributed evenly over a surface of $(1.69)^2 \times 3.142 = 8.95$ square in.

Results

Preliminary Trials With Two Types of Soiled Fabric. Two types of soiled textile fabric were used in preliminary trials of the soil removal in distilled water and detergent solution. The first was a printed type of soiled swatch, obtained from the General Dyestuffs Corporation, and the second was a standard soiled fabric prepared by the immersion of white Indianhead muslin (which has been carefully desized and conditioned) into a soiling medium comprising carbon black, lubricating oil, and vegetable fat dispersed in Stoddard Solvent. The immersion is carried out in a small washer; 10 yards of fabric were soiled per batch. The fabric is rinsed, aged, washed lightly to remove loosely held surface soils, and adjusted to a specific reflectance. One swatch from every yard soiled is examined for ease of soil removal by five standard washings. Soiled cloth not showing soil removal within definite limits is rejected. This soiled cloth is distributed nationally and abroad by Foster D. Snell Inc., New York, 11, N. Y. This soil, called TSCW cloth, has been developed by Mack, Oesterling, and associates at the Pennsylvania State University and has been used continuously in research and testing for about 27 years. It is prepared presently in the laboratories of the first-named author.

In these preliminary trials the print type of soiled fabric required a lesser energy output for removal of soil from its surface than did the fabrics soiled by the immersion technique. The question arose however as to whether the soil on the former represented a surface coating rather than soil which had an intimate association with the fabric.

With both types of soiled cloth, removal in distilled water alone through a wide range of temperatures from room temperature to about 160°F. effectuated only a narrow range of brightness regain values. When a 0.1% solution of neutral soap (titre 32–34° C.) was employed, on the other hand, the brightness regain was greatly increased. For example, it will be recalled that there is expended over the work area of 8.95 sq. in. a power of 0.158 watts for a period of 563 seconds. This is equivalent to an energy output of 89 joules (watt-seconds). Using the printed type of soiled cloth, it was found that 89 joules resulted in brightness regain of 28.3% in distilled water while the addition of 0.1% of the neutral soap produced a brightness regain of 62.4%. Thus it may be stated that in distilled water this soiled cloth will yield its soil at an energy of 3.15 joules per unit of brightness regain whereas the addition of 0.1% of a neutral soap reduces this requirement to 1.43 joules per unit brightness regain.

With an energy output of 89 joules a brightness regain of 12% was obtained in distilled water at 160°F. or 7.4 joules per unit of brightness regain, using TSCW soiled cloth. At 100° F. in distilled water for TSCW cloth the joules per unit of brightness regain were 9.9.

Preliminary Trials With Three Alkyl Aryl Sulfonates. Three alkyl aryl sulfonates have been selected for preliminary measurements of the amount of work required to remove soil from TSCW cloth at 160°F., using different concentrations of the detergent. These are the following: sodium n-tetradecyl phenyl sulfonate, $C_{14}H_{29}(C_6H_4)SO_3Na$; sodium n-dodecyl phenyl sulfonate, $C_{12}H_{25}(C_6H_4)SO_3Na$; and sodium n-nonyl phenyl sulfonate, $C_9H_{19}(C_6H_4)SO_3Na$. These compounds were prepared in the chemical laboratories of the Texas State College for Women. Intermediate and final products were isolated and purified, with melting point or boiling point and refractive index determined.

Figure 3 gives a graphic summary of the detergency results obtained with these three organic compounds. It will be noted that brightness regain accomplished

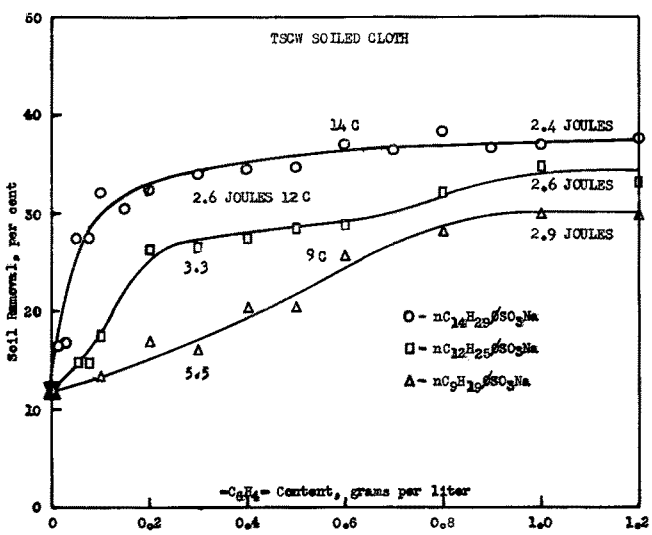

FIG. 3. Soil removal with ultrasonic cone transducer produced by the alkyl aryl sulfonates at various concentrations.

by the three respective straight chain alkyl aryl sulfonates improved with an increase in molecular weight. For any one compound the extent to which increases in detergency results accompany increases in concentration of the detergent may be noted.

The data in Figure 3 show that a maximum soil removal has been approached for $C_{14}H_{29}(C_6H_4)SO_3Na$ expressed as $-C_6H_4-$ at 0.03%, with little increase for concentrations beyond this point. Table III reveals the fact that a reduction in work energy takes place until the 0.03% concentration of $-C_6H_4-$ has been reached, again with little change for higher concentrations.

TABLE III

Values of Bonding Energy (Joules Per Unit Soil Removal) For Three Alkyl Aryl Sulfonates TSCW Soiled Cloth

Concentration, gm. $-C_6H_4-$ per l.	Joules per Unit Brightness Regain		
	Sodium n-Nonyl Phenyl Sulfonate	Sodium n--Dodecyl Phenyl Sulfonate	Sodium n-Tetradecyl Phenyl Sulfonate
0.05	....	6.0	3.2
0.07	....	6.0	....
0.075	....	....	3.2
0.10	6.7	5.1	2.8
0.20	5.3	3.4	2.8
0.30	5.5	3.3	2.6
0.40	4.4	3.2	2.6
0.50	4.3	3.1	2.5
0.60	3.4	3.1	2.4
0.70	....	....	2.4
0.80	3.2	2.7	2.3
0.90	....	....	2.5
1.00	2.9	2.6	2.4
1.10	....	....	2.6
1.20	3.1	2.7	2.4
1.25	....	....	2.4

The remarkable agreement in the data for $C_9H_{19}(C_6H_4)SO_3Na$, $C_{12}H_{25}(C_6H_4)SO_3Na$, and $C_{14}H_{29}(C_6H_4)SO_3Na$ are apparent from examination of Figure 3. Insofar as the data for $C_{12}H_{25}(C_6H_4)SO_3Na$ are concerned, a levelling-off of the curve for soil removal *versus* $-C_6H_4-$ concentration occurs at a later stage than is apparent for $C_{14}H_{29}(C_6H_4)SO_3Na$ and at a correspondingly earlier stage than for $C_9H_{19}(C_6H_4)SO_3Na$. This would tend to indicate generally increasing detergent power for increasing carbon content of these synthetic detergents as chain length increased from C_9 to C_{14}.

With respect to $C_9H_{19}(C_6H_4)SO_3Na$ far lower detergency values are obtained at all concentrations, with concurrent higher work output per unit of soil removal. The maximum soil removal and the minimum energy output occurs at about 1.0 g. per liter $-C_6H_4-$ concentration; and the amount of soil removal is far less than that at about one-third the concentration of the longer carbon chain compound.

Preliminary Trials With a Neutral Low Titre Soap. Figure 4 shows the soil removal data for a low titre soap with which no alkaline builder was used, in terms of the percentage of soil removal efficiency and the joules of energy required per unit of soil removal.

As in the case of the best of the three alkyl aryl sulfonates which have been studied on a preliminary basis, an approach to the optimum soil removal has been reached at a moderately low concentration of soap (0.04% as Na_2O), after which little improvement in soil removal has been effectuated. A concurrent decrease in work required per unit soil removal likewise proceeds through 0.04% Na_2O concentration, after which no change is noted.

The same soap was used in practical soil removal trials. A mechanical washer fitted with 1-gal. jars

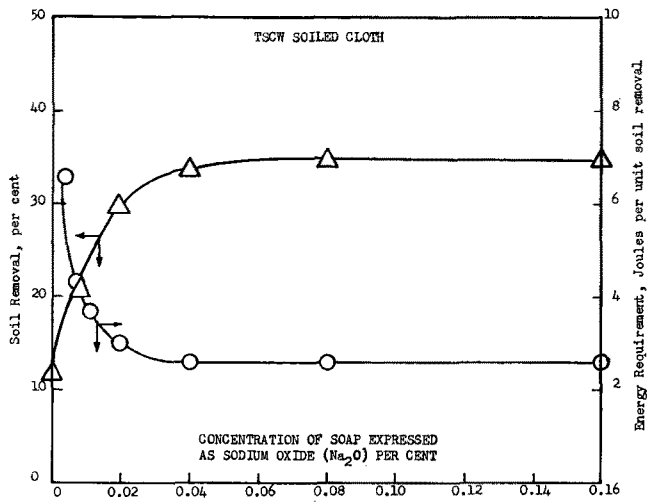

FIG. 4. Soil removal with ultrasonic cone transducer produced by a low titer soap (without alkaline builder) at various concentrations.

given an end-over-end motion was employed to provide mechanical action. Thirty consecutive washing procedures of 20 min. each were required to effectuate similar levels of brightness regain for the respective concentrations of soap.

A limited amount of data was obtained by ultrasonic cleaning of soiled TSCW swatches in distilled water at room temperature. Indications are that soil removal is a parabolic function of the energy output in joules. This relationship requires further investigation.

The value of this experimental procedure is demonstrated in the marked reduction in time required to assess the efficiency of any given detergent. In the example cited tests in the mechanical washer requiring 4,800 min. can be effectuated in about 80 min., using the dynamic detergency tester.

It is further to be emphasized that this time reduction is brought about with no sacrifice in precision of measurement.

Summary

Work on the magnitude of forces binding soils to textile surfaces has been described. In these studies an ultrasonic transducer has been used as a means for providing mechanical action of precisely controlled magnitude. Results have revealed energy requirements for any given level of soil removal. In addition, precision over existing methods of evaluation of detergents and detergency procedures is increased with considerable decrease in time of test.

Acknowledgment

The authors are indebted to the Office of the Quartermaster General for financial assistance so generously given in support of this work. The imaginative suggestions and criticisms of Pauline Beery Mack, dean of the College of Household Arts and Sciences at the Texas State College for Women are deeply appreciated, and thanks are extended to her. The authors also are indebted to John A. Balog and Miss Helen A. Ludeman for assistance in laboratory manipulation and synthesis of compounds used. Finally, thanks are extended to the Clevite-Brush Development Company for technical guidance concerning the operating characteristics of the cone transducer and electronic driver.

[Received July 19, 1955]