APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Feb. 1983, p. 591–597
0099-2240/83/020591-07$02.00/0

Vol. 45, No. 2

Bacteriological Quality of Fabrics Washed at Lower-Than-Standard Temperatures in a Hospital Laundry Facility

ROBERT R. CHRISTIAN,†* JANET T. MANCHESTER,‡ AND MICHAEL T. MELLOR§

Department of Biological Sciences, Drexel University, Philadelphia, Pennsylvania 19104

Received 1 June 1982/Accepted 10 November 1982

We determined whether the bacteriological quality of fabrics cleaned in a hospital laundry could be maintained at wash temperatures lower than 75°C by the use of economically reasonable formulas and wash conditions. Three groups of bacteria were examined to determine bacteriological quality: aerobic, nonexacting chemoorganotrophs, staphylococci, and total coliforms. The distribution of bacteria on soiled fabric was patchy, with staphylococci and total coliforms ranging from <0.1 to $>4 \times 10^3$ CFU/cm^2 and chemoorganotrophs ranging from <0.1 to $>5 \times 10^5$ CFU/cm^2. The washing process routinely produced fabric containing <1 CFU/cm^2. Low-temperature (47.8 to 60.0°C) wash procedures eliminated all bacterial groups at least as effectively as did high-temperature procedures. The effectiveness of bacterial density reduction at low temperatures was augmented by increased concentrations of bleach. Successful low-temperature washing such as that shown here may save both energy and money for hospitals.

Laundering may account for 50 to 75% of the energy used to heat water in hospitals (Minnesota Legislative Science and Technology Research Office, Inquiry Response no. 89, 26 September 1979). Many hospitals follow the recommendations of the American Hospital Association (1) or state requirements (13) by maintaining wash water temperatures at 71°C (160°F) or higher. These recommendations and regulations are largely the result of a 1938 report by Arnold (3), who found few sanitary problems when temperatures of 74 to 79°C (165 to 175°F) were used in commercial laundries. Subsequent studies have shown that the use of 60 to 65°C water for normal wash periods is sufficient to ensure the elimination of bacteria associated with nosocomial infections (6, 9, 13, 15). Most studies of temperature effects on bacterial elimination used cloth inoculated with pure cultures. Less is known about the effect of wash conditions on the normal microbiota found in fabric sent to the hospital laundry (13). Energy, and hence money, could be saved if the wash temperature were to be lowered without compromising the bacteriological quality of the clean fabric. If energy costs are to be reduced in the future by lowering wash water temperatures, the laboratory studies must be corroborated by field studies to ensure the maintenance of bacteriological quality.

The purpose of this research was to determine whether the bacteriological quality of clean fabric processed in a hospital laundry could be maintained at wash temperatures lower than 75°C by the use of economically reasonable formulas and wash conditions. Little is known about the bacterial densities normally associated with fabrics in a hospital laundry either before or after washing. This represents the first extensive study in which current and complete wash formulas were examined for their effectiveness on the bacteria that occur naturally on fabric in a hospital setting. In this study, the bacteriological quality of fabric washed by standard procedures was determined as a base line of acceptability for comparison with the effectiveness of modified wash conditions. Lowering wash temperatures in a hospital laundry may compromise the effectiveness of the products normally used. If the wash temperature is to be lowered, we reasoned that another sanitary barrier must be increased in potency to ensure the continued protection of the patients. Thus, the chlorine dosage was increased and formulas were altered as wash temperatures were lowered. The resulting analyses of bacteriological quality evaluated the effectiveness of the modified conditions compared with normal conditions (standard 75°C wash). Tests for final bacteriological quality did not include any linen that had been

† Present address: Biology Department, East Carolina University, Greenville, NC 27834.
‡ Present address: 8 Mt. Vernon Dr., Clayton, DE 19703.
§ Present address: 6522 American Street, Philadelphia, PA 19126, or contact through Diversey-Wyandotte, 1532 Biddle Avenue, Wyandotte, MI 48192.

TABLE 1. Wash temperatures and formulas for sampling dates

Date (mo/day/yr)	Wash temp (°C)	First detergent (kg)[a]	Bleach (kg) (chlorine concn)[b]	Second detergent (kg)	Sour (kg)	Softener (kg)
4/30/81	75.6	Matrix (0.91)	Due-White, 0.23 (50)	Matrix (0.06)	Adjust-S (0.17)	Sanisorb (0.17)
5/6/81	73.9	Matrix (0.68)	Due-White, 0.23 (50)		Adjust-S (0.17)	Sanisorb (0.17)
5/13/81	76.7	Matrix (0.68)	Due-White, 0.23 (50)	Matrix (0.17)	Adjust-S (0.17)	Sanisorb (0.17)
5/18/81 (two washes)	76.7	F-101 (0.91)	Halox, 0.11 (32)	F-101 (0.11)	Klera-Cid (0.11)	Issue Plus (0.13)
5/20/81	76.7	F-101 (1.36)	Halox, 0.51 (146)		Klera-Cid (0.11)	Issue Plus (0.13)
5/27/81	60.0	F-101 (1.36)	Halox, 0.87 (250)		Klera-Cid (0.11)	Issue Plus (0.13)
6/3/81	57.2	F-101 (0.91)	Halox, 0.11 (32)	F-101 (0.11)	Klera-Cid (0.11)	Issue Plus (0.13)
6/10/81	48.9	F-101 (0.91)	PD-4580, 0.58 (125)	F-101 (0.28)	Adjust-S (0.17)	Sanisorb (0.17)
6/15/81 (two washes)	60.0	F-101 (0.91)	F-401, 1.16 (250)		Adjust-S (0.17)	Sanisorb (0.17)
6/17/81	60.0	F-101 (0.91)	F-401, 0.58 (125)		Adjust-S (0.17)	Sanisorb (0.17)
6/24/81	48.9	F-101 (1.36)	F-401, 1.15 (250)	F-101 (0.45)	Adjust-S (0.17)	Sanisorb (0.17)
6/30/81	50.0	F-101 (0.91)	PD-4580, 0.58 (125)		Adjust-S (0.17)	Sanisorb (0.17)
7/2/81	47.8	F-101 (1.36)	PD-4580, 0.58 (125)	F-101 (0.45)	Adjust-S (0.17)	Sanisorb (0.17)
7/8/81	48.9	F-101 (0.91)	F-401, 0.58 (125)		Adjust-S (0.17)	Sanisorb (0.17)
7/28/81	77.2	F-101 (0.91)	Halox, 0.11 (32)	F-101 (0.11)	Adjust-S (0.17)	Sanisorb (0.17)

[a] Quantity added per wash load.
[b] Values in parentheses are the resulting concentration of chlorine in micrograms per milliliter.

processed through a flatwork ironer or dryer, since some institutions do not have ironers and certain laundered items are not subjected to high dryer heat.

MATERIALS AND METHODS

Sample collection. All samples were collected from the laundry facilities of the Medical College of Pennsylvania Hospital, Philadelphia, Pa. Three types of cloth were used for analyses: 100% cotton plain weave (cotton), 50% cotton–50% polyester (cotton blend), and the more bulky looped, pile-weave cotton from towels (terry cloth). Most analyses were performed on cottons or cotton blends, which were representative of the bulk of hospital linen. Before-wash samples were collected from soiled fabric sent to the laundry facility. We selectively sampled the most visibly soiled laundry in an attempt to obtain worst-case conditions of bacterial contamination. The chosen sample cloth was cut in half. Two 50-cm^2 swatches were cut from each half aseptically with sterile pinking shears. Thus, from one cloth we obtained duplicate samples of two swatches each. The remainder of each half of the cloth was placed into a loose-mesh nylon bag and washed with other laundry under appropriate conditions. Immediately after being washed, two swatches from each half were collected as before. On three occasions samples were taken during the wash cycle before bleach was added.

Each pair of cotton or cotton blend swatches was placed into 20 ml of sterile neutralizer solution containing lecithin, Tween 80, and phosphate buffer to prevent the inhibitory activity of quaternary ammonium bacteriostatic agents (4). For terry cloth samples, one swatch was placed into 10 ml of the solution. The samples were transported to the laboratory in an ice chest at <10°C and stored in this condition until analyzed. The maximum length of time from sampling to analysis was 6 h.

Laboratory analyses. Each sample was removed from the neutralizer solution and cut aseptically into four or five pieces into a sterile Waring blender. The neutralizer solution which contained the sample was added along with 80 ml of a sterile rinse solution containing PET buffer (0.1% peptone, 0.1% Tween 80, and 0.01% EDTA); 90 ml of PET buffer was added for the terry cloth samples. Some of the measured volume of PET buffer was first used to wash the sample vial and then poured into the blender. The contents were blended for 60 s. The liquid was filtered through sterile cheesecloth to remove fibers, and the filtrate was used for bacterial analyses. Between macerations the blender was sterilized with 70% ethanol and sterile rinse water and by exposure to UV light for at least 30 min. The maceration-filtration procedures were found to recover more than 85% of either *Escherichia coli* or *Staphylococcus aureus* organisms inoculated onto the swatches before blending (Christian and Todd, unpublished data).

Three groups of bacteria were evaluated. Aerobic, nonexacting chemoorganotrophs were enumerated from growth on Trypticase-glucose extract agar (TGEA) (BBL Microbiology Systems, Cockeyville, Md.), staphylococci on Chapman-Stone agar (CSA) (Difco Laboratories, Detroit, Mich.), and total coliforms on m-Endo medium (Difco) (2). Membrane filtration procedures were used for all three groups. Volumes of 0.1, 1.0, or 10 ml of filtrate from the cheesecloth were filtered through 0.45-μm pore size GN-6 filters (Gelman Sciences, Inc., Ann Arbor, Mich.). Not all volumes were used for each sample. Smaller volumes were diluted with sterile rinse water in the filter funnel to insure proper dispersion of

TABLE 2. Base-line bacterial densities on soiled fabric in a hospital

Bacterial group (no. of samples)	No growth (%)[a]	Density (CFU/cm²) range[b]				
		Minimum	25%	50%	75%	Maximum
Aerobic chemoorganotrophs (51)	3.9	<0.09	4.7	124.3	$>2.5 \times 10^4$	$>5 \times 10^5$
Total coliforms (48)	45.8	<0.09	<0.09	<0.18	12.7	$>6.0 \times 10^3$
Staphylococci (51)	13.7	<0.09	0.5	8.5	73	$>4.4 \times 10^3$

[a] Percentage of samples giving no growth on plates.
[b] Densities represent the values at each quartile and the minimum and maximum densities based on the frequency distribution of results.

bacteria on the filters. In addition, spread plates of 0.01 and 0.1 ml on TGEA were made for the before-wash samples. The membranes were placed on the appropriate medium and incubated at 35°C for 48 h on TGEA, at 30°C for 48 h on CSA, and at 35°C for 24 h on m-Endo. The quality assurance procedures for the filtering techniques were those described by Christian and Pipes (5) and elsewhere (2).

All colonies were counted on TGEA and CSA. Colonies on CSA were clear or pale cream and yellow. Thirty-six clear or pale cream and nine yellow colonies from 27 individual samples were selected for confirmation on Baird-Parker medium. Only three of the former and five of the latter colony types were confirmed as *S. aureus*. However, all of the colonies were gram-positive cocci; thus, for our analyses we used all colonies as a presumptive identification for the staphylococci group. Only colonies with a green metallic sheen on m-Endo medium were considered total coliforms. Eight colonies were selected for confirmation (2), and all were confirmed as coliforms.

Equipment. Laundering was done in American Laundry Machinery Cascadex Washer-Extractors, model 6036. The rate capacity of the equipment was 350 lb (159 kg) of linen (dry weight). However, the soiled linen was weighed and loaded at 300 lb (136 kg) per wash load, following routine hospital laundry procedures.

Wash conditions. Samples were collected on 16 occasions. The wash formulas for each occasion are listed in Table 1. The temperatures used ranged from 47.8 to 77.2°C. The basic wash operation consisted of one detergent bath, generally 8 min long. If the expected amount of soil in the load was excessive, this regular detergent bath was preceded by another detergent bath called a break operation, generally 6 min long. The break was followed by a rinsing operation called a flush. The use of this additional detergent bath is a standard procedure for washing more heavily soiled loads.

Two detergents were used: Matrix (Service Master, Downers Grove, Ill.), an alkaline synthetic detergent, and F-101 (Diversey-Wyandotte Corp., Wyandotte, Mich.), an alkaline synthetic detergent designed specifically for low-temperature washing. The low-temperature detergent, F-101, is a synergistic blend of selected surfactants, alkalies, emulsifiers, and an anti-redeposition agent. Detergent effectiveness in stain removal and other visual determinations of cleanliness are temperature dependent. Products designed for use at 75°C may have a reduced capability at lower temperatures. The detergents and wash procedures used here were selected as representative of those providing the visual appearance (e.g., whiteness) required.

Four different chlorine bleaches were used: Due-White (Service Master) and Halox, PD-4580, and F-401 (Diversey-Wyandotte). All four bleaches contained organic chlorine. Added bleach produced an initial concentration ranging from 32 to 250 μg of available chlorine per ml. The initial concentration was determined by calculating the water volume, weight of added bleach, and the available chlorine of each bleaching agent. The duration of bleaching ranged from 8 to 11 min. Occasionally a rinsing operation (flush) preceded the bleach operation to lower the pH of the solution to between 9 and 10 for proper bleach activity. A series of three rinses followed the bleach operation to rid the linen of detergents and bleach.

After the load was rinsed, a sour/softener operation was used. The sours were Adjust-S (Service Master) and Klera-Cid (Diversey-Wyandotte) and the softeners were Sanisorb (Service Master) and Issue Plus (Diversey-Wyandotte). This procedure was routine at

TABLE 3. Comparison of aerobic chemoorganotroph densities after washes at three temperatures[a]

Wash temp (°C)	No. of samples	No growth (%)[b]	Chemoorganotroph density (CFU/cm²) range		
			Minimum	Median	Maximum
73.9–77.2	21 (15)	9.5 (6.7)	<0.1 (<0.1)	0.2 (0.1)	>167 (4)
57.2–60	16 (16)	87.5 (87.5)	<0.1 (<0.1)	<0.1 (<0.1)	0.2 (0.2)
47.8–50	16 (16)	75.0 (75.0)	<0.1 (<0.1)	<0.1 (<0.1)	0.7 (0.7)

[a] Samples taken on two occasions had anomalously high densities (see the text). The analysis was made both with and without these breakthrough samples. Each value given in parentheses represents the results obtained when the breakthrough samples were excluded from analysis. The Kruskal-Wallis test parameter (H) was 18.81 (13.37 with breakthroughs excluded); the probability of equality was <0.005 in both cases.
[b] Percentage of samples giving no growth on plates.

TABLE 4. Comparison of densities of total coliforms and staphylococci after washes at three temperatures[a]

Organism	Wash temp (°C)	No. of samples	No growth (%)[b]	Bacterial density (CFU/cm²) range		
				Minimum	Median	Maximum
Total coliforms	73.9–77.2	20	85	<0.05	<0.1	<1
	57.2–60	16	100	<0.1	<0.1	<0.2
	47.8–50	16	100	<0.02	<0.1	<0.1
Staphylococci	73.9–77.2	21	76.2	<0.09	<0.1	>100
	57.2–60	16	87.5	<0.1	<0.1	0.2
	47.8–50	16	93.8	<0.1	<0.1	0.5

[a] The Kruskal-Wallis test parameter (H) was 2.48 and 4.13 for total coliforms and staphylococci, respectively; the probability of equality was $0.5 > P > 0.1$ for both.
[b] Percentage of samples giving no growth on plates.

any temperature. Sour is a mildly acidic material (fluorine compound) used to neutralize residual detergent in the linen and to adjust the pH to a slightly acidic condition (pH 5.4 to 6.0). The fabric softener with bacteriostatic properties (quaternary ammonium compounds) was used in the same manner for all temperatures.

Statistical analyses. The distribution of bacteria was found to be patchy. As a result, nonparametric descriptive and test statistics were used (12). The median was used as a measure of the central tendency of bacterial densities in lieu of the mean, and variability was assessed by the components of the range. Data are presented as the percentage of samples with no growth; the minimum, median, and maximum densities obtained; and, in some cases, the densities at the 25 and 75% quartiles. Testing of the null hypotheses of treatment effects was done by the Kruskal-Wallis test adjusted for ties in ranks (12). This test is a nonparametric equivalent to a one-way analysis of variance, in which densities are first ranked in increasing order and the distribution of ranks between treatments is assessed. Bacterial densities were converted to CFU per square centimeter, where 1 ml of fluid from maceration was equal to 1 cm^2 of cloth for the cotton and cotton blend samples (1 ml equaled 0.5 cm^2 for the terry cloth samples). For hypothesis testing, the minimum density of detection was taken as 0.1 CFU/cm^2.

RESULTS

A summary of the bacterial densities found on the soiled fabrics is given in Table 2. Almost all of the soiled cloths (96.1%) possessed some detectable bacteria. The lower limits of detection ranged from 0.09 to 0.18 CFU/cm^2 for all groups, depending on the volume filtered and the quantity of cloth per sample. As expected, aerobic chemoorganotrophs were most commonly detected. Staphylococci were found in 86.3% of the samples, and total coliforms were detected in slightly more than half of the samples (54.2%). The median densities (50% column) of the groups followed the same order of abundance: aerobic chemoorganotrophs > staphylococci > total coliforms. The maximum density obtained for all groups on soiled fabric exceeded 10^3 CFU/cm^2. Thus, the range of bacteria from minimum to maximum density for any group exceeded 10^4 CFU/cm^2, and the range for aerobic chemoorganotrophs was greater than 10^6 CFU/cm^2.

Samples were collected over a 3-month period. If the following tests for wash effectiveness are to be valid, before-wash densities should not have changed systematically over that time period. To assess this possibility, we performed Kruskal-Wallis tests among the before-wash bacterial densities for three wash temperature groupings: washes from 73.9 to 77.2, 57.2 to 60.0 and 47.8 to 50.0°C. The test statistics (adjusted H) (12) for aerobic chemoorganotrophs, staphylococci, and total coliforms were 5.31, 5.41, and 3.37, respectively. The null hypothesis that before-wash densities were the same at all temperatures could not be rejected at the 0.05 level for any of the bacterial groups. Thus, no systematic changes in the density of bacteria on soiled fabric were found between the times of the different wash conditions.

By comparing Table 2 with Tables 3 and 4 it can be seen that washing greatly reduced bacterial densities. A larger percentage of the after-wash samples showed no detectable bacterial growth, and the median and maximum densities were reduced with washes at all temperatures for all bacterial groups. Negative logarithmic reduction analyses (6) were not appropriate measures of wash condition effectiveness in our design because of the patchiness of densities in soiled samples. Pairing of before- and after-wash samples provided an inordinately wide range of negative logarithmic reduction values (data not shown). Thus, the following hypothesis was tested by comparing after-wash densities under different wash conditions. The null statistical hypothesis was that the densities derived from all wash conditions were the same. The hypothesis restated for public health significance is that the wash conditions at low (47.8 to 60°C) temperatures provided a bacteriological quality for clean fabric no worse than that attained at standard wash temperatures (73.9 to 77.2°C).

The minimum, median, and maximum densities of chemoorganotrophs after a wash at nor-

TABLE 5. Comparison of aerobic chemoorganotroph densities after washes at different available chlorine concentrations during bleaching[a]

Available chlorine concn (μg/ml)	No. of samples	No growth (%)[b]	Chemoorganotroph density (CFU/cm²) range		
			Minimum	Median	Maximum
≤50	23 (19)	21.7 (21.1)	<0.1 (<0.1)	0.1 (0.1)	>60 (4.0)
125–150	20 (18)	70.0 (77.8)	<0.1 (<0.1)	<0.1 (<0.1)	>167 (0.7)
250	10 (10)	90.0 (90.0)	<0.1 (<0.1)	<0.1 (<0.1)	<0.2 (<0.2)

[a] Samples taken on two occasions had anomalously high densities (see the text). The analysis was made both with and without these breakthrough samples. Each value given in parentheses represents the results obtained when the breakthrough samples were excluded from analysis. The Kruskal-Wallis test parameter (H) and the probability of equality were 6.66 and $0.05 > P > 0.025$ for all samples and 8.74 and $0.25 > P > 0.01$ with the breakthrough samples excluded.

[b] Percentage of samples giving no growth on plates.

mal temperatures were <0.1, 0.2, and >167 CFU/cm², respectively (Table 3). On two consecutive samples, large densities of yellow colonies were found on after-wash TGEA plates. These were found during the wash cycle on one occasion. They were not found on CSA or m-Endo medium, nor were they observed on any other occasion. The isolates were gram negative, oxidase negative, and catalase positive. Attempts to identify the organism with the API-20E system (Analytab Products, Plainview, N.Y.) were unsuccessful. Great care was taken to insure sterility and aseptic procedures. We assume that these organisms were the result of breakthrough contamination during the wash in lieu of evidence to the contrary. We define breakthrough contamination as the survival of inordinately high densities of bacteria during washing. We analyzed our data both with and without the inclusion of these samples to allow for the possibility of laboratory contamination. The median and maximum densities were lowered to 0.1 and 4.0 CFU/cm², respectively, by excluding these samples.

The probability of equal chemoorganotroph densities between the various wash temperatures was $P < 0.005$ for both sets of data from the high-temperature wash (Table 3). The significant differences were a result of lower densities from the intermediate- and low-temperature wash samples compared with those from standard wash temperatures. There were greater percentages of samples with no growth and lower median and maximum densities at the two lower temperatures than at the high temperature. There were no significant differences in density for either total coliforms or staphylococci between the cloths washed at the three temperatures (Table 4). Most samples contained <0.1 CFU/cm² for either bacterial group. In fact, total coliforms were undetectable in any sample from the two lower temperatures, and staphylococci were undetectable in >87.5% of these samples.

Wash formulas were altered throughout the study so that temperature was not the sole variable. One other important variable was the initial available chlorine concentration. As shown in Table 1, the concentrations of bleach and chlorine were generally higher at low and intermediate than at high temperatures. For this reason the relationship between chemoorganotroph density and chlorine concentration was investigated (Table 5). Initial chlorine concentrations were grouped into three categories: <50, 125 to 150, and 250 μg/ml. Significant differences in bacterial density were found between these categories ($0.05 > P > 0.025$ for all samples, $0.025 > P > 0.01$ with breakthrough contamination samples excluded). The lowest chlorine concentration category was represented by the lowest percentages of no growth and the highest median densities.

DISCUSSION

Each of the three bacterial groups was monitored for specific purposes. The staphylococci include *S. aureus*, a known agent in certain nosocomial diseases (7, 10) and a species used previously in similar studies (6, 13, 15, 16). Total coliforms were monitored as indicators of fecal contamination (2) and as gram-negative organisms to compare with the gram-positive staphylococci. The aerobic, nonexacting chemoorganotrophs were monitored as the most general grouping of bacteria that might include other species important in nosocomial diseases (e.g., *Pseudomonas aeruginosa* and *Serratia marcescens*). All three groups displayed considerable density variability in soiled fabric. Maximum variations in density ranged over four to six orders of magnitude. Such variability has been demonstrated previously for soiled fabric in a hospital by Walter and Schillinger (13), using tryptic soy agar plus 0.5% yeast extract. These authors suggested that 0.2 CFU/cm² for "properly laundered and stored linens" is a reasonable

goal for the laundry process. Our results were obtained for the most visibly soiled material that we could find. If bacterial densities are highest in areas of visible stains (13, 14), maximum viable densities before washing may be considered to be at least 5×10^5 CFU/cm^2. Thus, to achieve the goal of 0.2 CFU/cm^2, any wash procedure or formula should insure a minimum of a 6 to 7 log elimination of bacteria.

Normal wash conditions (73.9 to 77.2°C) generally insured chemoorganotroph densities below 1 CFU/cm^2 and total coliform and staphylococci densities below 0.1 CFU/cm^2. These values may be taken as a base line for normal wash effectiveness. We are aware of no data from hospital laundries with which we may compare these values. Our data are, however, in reasonable agreement with the results of Walter and Schillinger (13). The breakthrough contamination observed on two consecutive occasions (2 days apart) was an exception to the normal bacteriological quality found. Although laboratory contamination cannot be ruled out, no reason for such contamination could be offered after investigating our procedures and the sterility of our materials. We present these data with reservation but in the interest of completeness, as too little is known about the hospital laundry environment to preclude the possibility of such breakthroughs. Their frequency and mechanisms of occurrence are unknown. If they do exist, they may represent a potential health problem to patients and a variable with which to contend in designing effective wash formulas.

The wash conditions at the two lower temperatures studied were equal to or more effective than those at high temperatures in eliminating bacteria. This effectiveness may have resulted in part from the altered formulas used at lower temperatures, in particular the increased concentration of chlorine. Others have suggested that washing for 5 to 13 min without bleaching at temperatures of 60°C or higher provides satisfactory removal of bacteria for health care facilities and that temperatures below this may compromise bacteriological quality (6, 13). Chemical disinfectants may overcome the loss of effectiveness of lower temperatures during the detergent cycle (8, 13, 15). As our study primarily monitored laundry after the entire process, we are unable to evaluate the importance of each individual mode of disinfection. Our purpose was to determine the feasibility of low-temperature washing with reasonable formulas.

The energy savings of low-temperature washing have been demonstrated in the commercial laundering business. The estimated energy savings with the lower-temperature formulas in the present study would be over 40,000 kcal (2×10^5 BTU) per washload. These savings would offset the increased chemical cost by providing an appreciable decrease in fuel costs. Aside from the chemical cost constraint, no low-temperature wash condition greatly lengthened the wash time relative to normal procedures. The formulas tested added about 2 to 3 min per load. In many cases, we observed an apparent reduction in the amount of linen that required rewashing because of stains. In addition, there was no indication of overt fabric damage. Our results confirm those of others in that effective washing below 74 to 79°C is possible and that chlorine may act as a significant sanitary barrier when temperatures are decreased.

Although we have shown that wash conditions at temperatures of 47.8 to 50.0°C may be as effective as those at higher temperatures in eliminating bacteria, caution is required for several reasons. First, we carefully monitored or controlled the cycling of the washer, the formula, and the water quality. Under routine use, such precautions may not be taken. When the disinfecting power of high temperature is removed, special safeguards may be required to ensure the effectiveness of other disinfection modes, such as bleaching. Second, viruses, other potentially resistant bacteria, and fungi may be on the fabric, and their elimination at low temperatures requires further investigation (9, 10). We found few endospores on fabric either before or after washing (unpublished data). The reliability of low-temperature washing in eliminating endospores needs special attention. Third, the observation of no growth on our plates was not an indication of sterility. It is unclear whether densities of certain pathogens below 0.1 CFU/cm^2 may still represent a potential health hazard. The potential savings in energy costs are great with low-temperature washes, but further evidence that the risks are acceptably low or absent is required before low-temperature laundering in hospitals will be generally accepted.

ACKNOWLEDGMENTS

This research was supported by Diversey-Wyandotte Corp.

We thank the Medical College of Pennsylvania for the use of their facilities and Doris Scott for her help at the laundry. We thank John Lopes, David Kane, and Barbara Barnes for their help and advice. We also thank Martin Tricarico for technical assistance.

LITERATURE CITED

1. **American Hospital Association.** 1968. Infection control in the hospital. American Hospital Association, Chicago.
2. **American Public Health Association.** 1975. Standard methods for the examination of water and wastewater, 14th ed. American Public Health Association, Inc., New York.
3. **Arnold, L.** 1938. A sanitary study of commercial laundry practices. Am. J. Public Health. **28**:839–844.
4. **Association of Official Agricultural Chemists.** 1975. Official methods of analysis. Association of Official Agricultural Chemists, Washington, D.C.

5. **Christian, R. R., and W. O. Pipes.** 1979. Recognition of subsequent contamination of samples from distribution systems with coliforms, p. 645–659. *In* American Water Works Association, Denver, Colo. Annual Conference Proceedings of the American Water Works Association.
6. **Jaska, J. M., and D. L. Fredell.** 1980. Impact of detergent systems on bacterial survival on laundered fabrics. Appl. Environ. Microbiol. **39**:743–748.
7. **Nahmias, A. J., and J. A. Shulman.** 1972. Epidemiologic aspects and control methods, p. 483–502. *In* J. O. Cohen (ed.), The staphylococci. Wiley-Interscience, Inc., New York.
8. **Nicholas, P. S.** 1970. Bacteria in laundered fabrics. Am. J. Public Health **60**:2175–2180.
9. **Ridenour, G. M.** 1952. A bacteriological study of automatic clothes washing. The National Sanitation Foundation, Ann Arbor, Mich.
10. **Shulman, J. A., and A. J. Nahmias.** 1972. Staphylococcal infections: clinical aspects, p. 457–482. *In* J. O. Cohen (ed.), The staphylococci. Wiley-Interscience, Inc., New York.
11. **Sidwell, R. W., G. J. Dixon, L. Westbrook, and F. H. Forziati.** 1971. Quantitative studies on fabrics as disseminators of viruses. V. Effect of laundering on poliovirus-contaminated fabrics. Appl. Microbiol. **21**:227–234.
12. **Sokal, R. R., and F. J. Rohlf.** 1969. Biometry. W. H. Freeman and Co., San Francisco.
13. **Walter, W. G., and J. E. Schillinger.** 1975. Bacterial survival in laundered fabrics. Appl. Microbiol. **29**:368–373.
14. **Wetzler, T. F., T. J. Quan, and K. Schatzle.** 1971. Critical analysis of the microflora of toweling. Am. J. Public Health **61**:376–393.
15. **Wilkoff, L. J., G. J. Dixon, L. Westbrook, and W. F. Happich.** 1971. Potentially infectious agents associated with shearling bedpads: effect of laundering with detergent-disinfectant combinations on *Staphylococcus aureus* and *Pseudomonas aeruginosa*. Appl. Microbiol. **21**:647–652.
16. **Wiksell, J. C., M. S. Pickett, and P. A. Hartman.** 1973. Survival of microorganisms in laundered polyester-cotton sheeting. Appl. Microbiol. **25**:431–435.