Marine Corps Cold Weather Sock System

Navy Clothing and Textile Research Facility
Natick, Massachusetts

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13. ABSTRACT *(Maximum 200 words)*

The Navy Clothing and Textile Research Facility was tasked by the Marine Corps Systems Command to conduct physical and thermal insulation testing on several commercial and standard socks, prior to and after laundering, using the current Navy shipboard procedure. Results obtained from this evaluation will provide Marine Corps baseline comparison for work concurrently tasked to the Natick Research, Development and Engineering Center(NRDEC). Based on test results, two sock systems were recommended as good candidates for use in cold weather.

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PROJECT TITLE: Marine Corps Cold Weather Sock System

TECHNICAL OBJECTIVE: To conduct physical and thermal insulation testing on several commercial and standard socks, prior to and after laundering, using the current Navy shipboard procedure. Results obtained from this evaluation will provide Marine Corps base line comparison for work concurrently tasked to the Natick Research, Development, and Engineering Center (NRDEC).

TEST SAMPLES:

Seven different sock types were selected for evaluation by the Marine Corps and procured by NCTRF. The sample types are described as follows:

A. 75/25% wool/cotton winter wool sock
Style: MIL-S-405
Source: Navy stock system
Cost: $2.80/pair
Color: Oatmeal
Reference Name: winter wool sock

B. 78/20/2% polyester/nylon/spandex Coolmax liner sock
Style: "Coolmax"
Source: DuPont
Cost: approx. $3.50/pair
Color: Black
Reference Name: Coolmax liner sock

C. 50/50% wool/polypropylene sock
Style: "All Weather Field Issue"
Source: Seneca
Cost: $9.00/pair
Color: Green
Reference Name: Seneca sock

D. 52/25/23% wool/nylon/cotton standard cushion sole sock
Style: MIL-S-48
Source: Navy stock system
Cost: $1.65/pair
Color: Black
Reference Name: cushion sole sock

E. 100% polyester fleece Polartec 200,
Style: "Feetheater"
Source: Wyoming Woolens
Cost: $9.99/pair
Color: Balsam
Reference Name: Feetheater sock

F. 100% worsted wool
Style: "Thermo"
Source: Wigwam
Cost: $6.00/pair
Color: grey/red
Reference Name: Thermo sock

G. 60% polyester/wool, 23% acrylic, 16% nylon, 1% spandex
Style: "SNB-13"
Source: Thorlo
Cost: $12.50/pair
Color: Black/grey
Reference Name: SNB-13 sock

TEST PROCEDURES:

Some of the commercial socks tested during this evaluation were designed specifically for a particular activity such as hiking or snowboarding. As a result, the candidate socks vary significantly with regard to fiber content and knit construction in different areas of the sock. To assess different areas of the socks for burst strength and thickness, five determinations were made for each of the locations indicated in Figure (1). Each of the tests were performed on each of the sample sock types, initially and after 20 laundering cycles using Navy Shipboard Formula III (see Appendix A).

1. Burst Strength:

This test was conducted in accordance with ASTM D3787, "Bursting Strength of Knitted Goods - Constant-Rate-of-Traverse (CRT) Ball Burst Test", which is intended to be used with knit and nonwoven materials. This test is used to determine the force required to rupture a material by distending it with a force under specified conditions.

Five socks of each sample type were tested before laundering and another separate five socks of each sample type were tested after 20 laundering cycles. This was done due to the destructive nature of the test. Each sock was tested in the following areas as illustrated in Figure 1: upper, instep, ball, arch, and heel.

2. Water Absorption (Dynamic):

This test was conducted in accordance with an in-house modified version of the AATCC-70 (1988), "Water Repellency: Tumble Jar Dynamic Absorption Test" method. The test procedure as written is intended to be used with fabrics, which may or may not have been given a water-resistant or water-repellent finish. However, for this

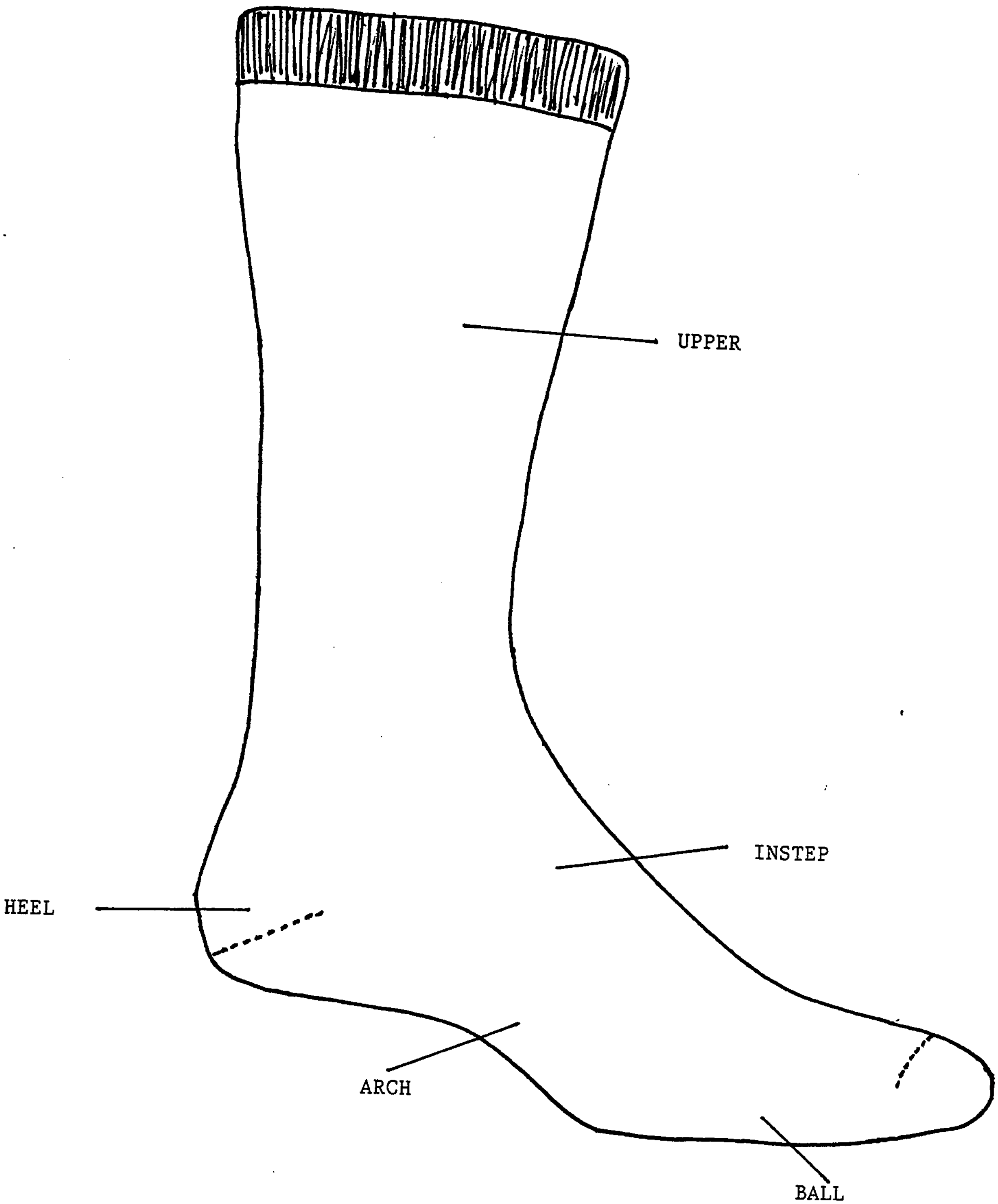

FIGURE 1

evaluation, the test procedure was modified to assess the "drying" ability of each candidate sock in standard atmospheric conditions (70^{o}, 65% relative humidity). Due to the sock's thickness, all socks were extracted for one minute in a centrifugal extractor in lieu of the specified rollers. After extraction was performed, each candidate sock was subjected to a series of timed weighings: initially (immediately after extraction), 30 minutes after extraction, and 60 minutes after extraction. Five socks of each sample type were tested before and after laundering.

3. <u>Thickness</u>:

This test was conducted in accordance with ASTM D1777, "Measuring Thickness of Textile Materials", which is intended to be used with all types of knit, woven, and nonwoven materials. "<u>Thickness</u> is the distance between the upper and lower surfaces of a material and is measured randomly under a specific pressure. Bulk and warmth properties of textile materials are often estimated from their thickness values."[1] For example, fabric thickness generally correlates well with its insulation properties. Generally, the thicker a fabric, the higher the expected insulation would be.

Five socks of each sample type were tested before and after laundering. Each sock was tested in the following areas as illustrated in Figure 1: upper, instep, ball, arch, and heel.

4. <u>Thermal insulation (clo)</u>:

To determine the thermal insulation values of the candidate socks, thermal foot testing was conducted. The NCTRF thermal foot is copper and is made in three sections to enable installation into boots. Each section is made of multiple plates so measurement of specific foot areas is possible. There are a total of twenty-seven plates and three guard sections, placed at the top of the sections, to keep heat from flowing from the side of the top plates. The thermal foot was used in an environmental chamber which was maintained at $20^{o}C$; thermal foot temperature was maintained at $26^{o}C$.

When testing, the thermal foot was outfitted with the appropriate sock and then, to provide realistic test data, a USMC Ski/March boot was donned over each sock or sock combination. A size 10-1/2 boot was used for all of the tests except for those with the Seneca sock (sample C),which required a larger boot size (11-1/2) to accommodate the thickness and non-compressibility and to achieve the same "fit" as with the other candidate socks. The thermal foot was then brought to equilibrium and insulation values were calculated based on heater resistance, heater voltage, plate area, and measured temperatures.

Three socks of each sample type were tested before laundering and another separate three socks of each sample type were tested after 20 laundering cycles. Since the "Coolmax" sock is intended to be worn as a sock liner in cold weather, it was tested in combination with two of the other socks: the winter wool sock (sample A) and the Seneca sock (sample C).

RESULTS/DISCUSSION

1. Burst Strength:

Results of the burst strength testing are reported in Table 1. With the exception of the Coolmax liner sock (sample B), burst strength for candidate socks increased or stayed the same after laundering. The Coolmax liner sock (sample B) lost an average of 22% burst strength after 20 launderings. The SNB-13 sock (sample G) would not burst in the ball and heel areas before laundering and would not burst in any of the tested areas after laundering. Rather, the test specimen elongated and hit the top of the specimen holder.

When comparing the test results for all candidate socks to the burst strength requirements found in military specification MIL-S-405 for the winter wool sock, and MIL-S-48 for the standard cushion sole sock, all candidates exhibited acceptable results, exceeding the specification requirement, 70 lbs. minimum, both before and after laundering.

2. Water Absorption (Dynamic):

Results of the water absorption testing are reported in Table 2. Results are expressed in terms of percentage weight gain based on the average dry weight of each sock type. This weight gain is directly due to the amount of water absorbed and retained by the socks following extraction. Reduction of this weight gain percentage over time reflects the drying of the socks under standard atmospheric conditions.

Moisture regain is a function of fiber type and is the amount of water that a bone dry fiber will absorb from the air under standard conditions of $70^{o}F$, 65% relative humidity. It is expressed as a percentage of the bone dry fiber. The higher the moisture regain value, the more absorbent the fiber. Each particular fiber has a known moisture regain value. When blends of fibers are used, the moisture regain value can be approximated based on the moisture regain values of each fiber and the percentage of that fiber present in the blend.

As seen in Table 2, the ability of a candidate sock to dry "quickly", was directly related to its fiber content and its respective moisture regain. The higher the moisture regain the

Table 1 - Burst Strength (lbs) of Candidate Socks Before and After Multiple Launderings

(Values represent the mean of five replications)

Winter Wool Sock (A)	Before Laundering	After Laundering
upper	80.6	145.6
instep	88.6	150.6
ball	82.4	144.6
arch	85.8	156.0
heel	79.2	122.7
average	83.3	143.9
std dev	3.8	12.7
% change		73%

Coolmax Liner Sock (B)	Before Laundering	After Laundering
upper	160.5	122.4
instep	150.0	127.2
ball	142.6	95.2
arch	155.0	121.0
heel	174.0	137.6
average	156.4	120.7
std dev	11.8	15.7
% change		-23%

Seneca Sock (C)	Before Laundering	After Laundering
upper	96.0	96.0
instep	98.0	101.0
ball	86.0	93.8
arch	95.0	95.8
heel	84.4	94.4
average	91.9	96.2
std dev	6.2	2.8
% change		5%

Cushion Sole Sock (D)	Before Laundering	After Laundering
upper	157.4	166.6
instep	159.6	165.6
ball	149.4	*
arch	155.4	*
heel	141.8	*
average	152.7	166.1
std dev	7.2	0.7
% change		*

Feetheaters (E)	Before Laundering	After Laundering
upper	87.0	98.0
instep	98.0	96.6
ball	99.8	97.2
arch	94.6	88.0
heel	98.8	95.4
average	95.6	95.0
std dev	5.2	4.0
% change		-1%

Thermo Sock (F)	Before Laundering	After Laundering
upper	93.0	104.2
instep	94.6	103.6
ball	85.0	100.0
arch	98.2	105.4
heel	109.4	144.0
average	96.0	111.4
std dev	8.9	18.3
% change		16%

SNB-13 Sock (G)	Before Laundering	After Laundering
upper	90.0	*
instep	110.2	*
ball	*	*
arch	119.0	*
heel	*	*
average	106.4	*
std dev	14.9	*
% change		*

* Specimen would not burst; elongated and hit top of sample holder.

Table 2 - Water Absorption AATCC-70 (Modified) - % Change from Dry Weight
(Values represent the mean of five replications)

	Immediately after AATCC-70 (weight gain - %)		30 minutes after AATCC -70 (weight gain - %)		60 minutes after AATCC-70 (weight gain - %)		
	Before Laundering	After Laundering	Before Laundering	After Laundering	Before Laundering	After Laundering	Moisture Regain (%)
Coolmax Liner Sock (B) 78/20/2 polyester/nylon/spandex	19.9	16.8	14.8	9.2	8.5	2.5	< 0.1
Feetheaters (E) 100% polyester	13.4	12.6	9.2	8.3	5.6	4.6	< 0.1
Seneca Sock (C) 50/50 polyester/wool	16.8	17.7	15.3	15.7	13.6	14.0	~ 6.5
SNB-13 Sock (G) 30/30/23/16/1 polyester/ wool/acrylic/nylon/spandex	21.1	20.1	19.0	16.7	15.9	13.5	~ 5.0
Winter Wool Sock (A) 75/25 wool/cotton	32.5	29.8	30.4	28.0	27.7	26.1	~12.0
Cushion Sole Sock (D) 52/25/23 wool/nylon/cotton	35.4	34.7	32.3	30.9	29.0	27.0	~10.0
Thermo Sock (F) 100% wool	32.6	32.5	27.5	29.3	24.5	27.1	~13.0

higher the water absorption percentages. As indicated in Table (2), the candidates can be loosely grouped into three levels of performance based on fiber content and similar moisture regain values. The two candidate socks with a low/nonexistent moisture regain, the Coolmax liner sock (sample B) and the Feetheater sock (sample E), absorbed the least amount of water and dried the quickest. These candidates are both comprised of 100% synthetic fiber. The Seneca sock (sample C) and the SNB-13 sock (Sample G) have somewhat higher moisture regains, due to the presence of a substantial amount of synthetic fiber blended with wool. These samples showed a higher amount of water absorption and took longer to dry than the first group as evidenced by the higher percentage of water weight gain still present after 60 minutes. The winter wool sock (sample A), the standard cushion sole sock (sample D), and the Thermo Sock (sample F) all have higher moisture regains since they contain high percentages of natural wool and cotton fibers. These samples showed the highest amount of water absorption and took the longest to dry of the three groups.

3. <u>Thickness</u>:

Average fabric thickness before and after shipboard laundering is reported in Table 3. The Seneca sock (sample C) was the only candidate sock thicker than the winter wool sock (sample A) before laundering. Laundering increased the average thickness of some of the socks (samples A, D, F, G), due to shrinkage, and the thickest sock after laundering was the winter wool sock (sample A).

4. <u>Thermal Insulation (clo)</u>:

Table 4 presents the results of the thermal foot tests. The thermal insulation values for the various socks and combinations are presented in clo units. The higher the clo value, the higher the thermal insulation, or resistance to heat transfer.

The control or bare foot value for all clo determinations was 0.2 clo. Clo values are reported as total values, i.e., they include the relatively still air layer adjacent to the surface of the boot. The values reported are the average of three independent measures.

Because test instrumentation like the thermal foot has such little inter-test variability, statistical significance between various socks is relatively easy to show. However, the significance of these differences is not always operationally - or noticeably - different to the wearer. A more practical method for analyzing the data is to use an arbitrary difference for concluding that items are better or worse than each other or when compared to standard items.

Table 3

Thickness (in) of Candidate Socks
Before and After Multiple Launderings

(Values represent the mean of five replications
of five different areas of the sock)

		Before Laundering	After Laundering
(A)	Winter Wool Sock	.156	.202
(B)	Coolmax Liner Sock	.033	.034
(C)	Seneca Sock	.185	.186
(D)	Cushion Sole Sock	.080	.093
(E)	Feetheaters	.107	.097
(F)	Thermo Sock	.102	.151
(G)	SNB-13 Sock	.109	.132

Table 4 - Thermal Foot Insulation Values (clo) of Candidate Socks
Before and After Multiple Launderings
(Values represent the mean of three replications)

	Before Laundering			After Laundering			
Item	avg clo	std dev	% diff from std	avg clo	std dev	% diff from std	% change due to laundering
A (std)	0.82	0.01	N/A	0.81	0.07	N/A	-2
A over B	0.87	0.01	6	0.89	0.03	10	3
C over B	0.97	0.02	18	0.98	0.03	21	1
C	0.91	0.01	10	0.93	0.01	15	2
D	0.64	0.01	-22	0.66	0.01	-18	3
E	0.75	0.08	8	0.64	0.03	-21	-15
F	0.84	0.01	2	not tested - sock shrank			
G	0.76	0.01	-8	0.73	0.01	-10	-4

The U.S. Army Research Institute of Environmental Medicine has suggested that for most applications, a 10% difference in clo could be used for evaluating whether items differ from each other.[2] Items that are within ±10% of a standard are considered equivalent. Items with thermal properties outside this 10% range are considered different. For purposes of this evaluation, the winter wool sock (sample A) was considered the standard to which all other candidates and combinations were compared.

Before Laundering: Using the above criteria, the Seneca sock with Coolmax liner (Sample C over B), and the Seneca sock alone (sample C) were rated superior to the winter wool sock alone (Sample A). Because they are more insulative, they would be expected to be warmer for a user in a cold environment. The winter wool sock with the Coolmax liner (sample A over B), the Feetheater sock (sample E), the Thermo sock (sample F), and the SNB-13 sock (sample G) were rated as equivalent to the winter wool sock alone (sample A). Only the cushion sole sock (sample D) was rated as inferior to sample A.

After Laundering: The Seneca sock with Coolmax liner (sample C over B), the winter wool sock with Coolmax liner (sample A over B), and the Seneca sock alone (sample C) were rated superior to the winter wool sock alone (sample A). Among these top three performers, the Seneca Sock with Coolmax Liner (C over B) was rated superior to the winter wool sock with Coolmax liner (A over B). The Thermo sock (sample F) shrank so much during laundering that it was not possible to test it because it would not fit on the foot. The Feetheater sock (sample E), the SNB-13 sock (sample G), and the cushion sole sock (sample D) were rated as inferior to the standard winter wool sock alone (sample A).

The Effect of Laundering: Table 4 also reports the effects of laundering on the clo values. Using the 10% difference as a criterion for significance, only the Feetheater sock (sample E) changed significantly as a result of laundering. All of the others remained the same in terms of thermal insulation, with the exception of the Thermo sock which was not tested after laundering.

CONCLUSIONS

The socks selected are intended for wear in a cold environment where minimizing body heat loss is a primary consideration. Therefore, it is desirable to select the item or combination which provides the greatest amount of thermal insulation (clo) and retains that insulation after multiple launderings. The Seneca sock with the Coolmax liner (sample C over B) provided the highest insulation value after laundering and was considered superior to the winter wool sock alone (sample A). The Seneca sock alone (sample C) and the winter wool sock with the Coolmax liner sock (sample A over B) were also superior to the winter wool sock alone (sample A). All three of these choices maintained thermal insulation values after 20 launderings.

If drying time is important, choosing socks and combinations which include substantial amounts of synthetic fiber will shorten the drying time. The Coolmax liner sock (sample B) dried quickly and in combination with the Seneca Sock (sample C over B) is a better choice than with the winter wool sock (sample A over B) because the Seneca sock (sample C) dried faster than the winter wool sock (sample A).

For durability, minimum levels of burst strength are required. Based on current military specification requirements for standard cold weather socks, all of the candidate socks meet minimum requirements for burst strength both before and after laundering.

RECOMMENDATIONS

Based on our testing, the Seneca sock with Coolmax liner combination (sample C over B) is recommended as the sock system of choice. However, because of its thickness, this selection would require the individual to wear a larger boot size. To avoid increasing the boot size, and to save cost (Seneca socks cost $9.00 per pair versus $2.80 per pair for standard wool socks), adding the Coolmax liner to the winter wool sock (sample A over B) would be a viable alternative. This selection will improve the thermal insulation of the wool sock alone once laundering has occurred. However, thermal insulation of this second choice is considered inferior to the first choice and drying time will be longer than with the Seneca sock.

ACKNOWLEDGMENTS

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1. Pizzuto, Joseph., "Fabric Science"; p275, 1977

2. Santee, W. R., L. A. Blanchard, S. K. W. Chang, and R. R. Gonzales. "Biophysical Model for Handwear Testing". U.S.Army Institute of Environmental Medicine. Tech Report #7-93, March 1993

APPENDIX A

NAVY WASH FORMULA III
LOW TEMPERATURE FORMULA
CLASSIFICATION: WOOLENS, SYNTHETIC, COTTON BLENDS, AND NONFAST COLORS

Step	Operation	Cycle Time (Minutes)	Water Temperature (Degrees Fahrenheit)	Water Level (Inches)	Supplies (100-lb Basis)	Notes
1	Break/suds	5	100 to 120	9	14 to 16 oz detergent oxygen bleach	A
2	Drain	1				
3	Flush/suds	5	100	9	4 oz detergent if required	
4	Drain	1				
5	Spin	1				
6	Rinse	3	90	9		
7	Drain	1				
8	Rinse	3	90	8		
9	Drain	1				
10	Sour	4	90	8	1.0 oz sour	
11	Drain	1				
12	Final Spin	4				

A. Detergent/bleach may be added to the wash wheel once the water level has been reached. Detergent amounts are based on a 100-lb basis and must be adjusted according to the size of the washer extractor used.

FOR SEAWATER WASHING

1. Use seawater in steps 1 and 3. Detergent bleach should be increased to 20 oz.

2. Use fresh water in steps 6, 8, and 10.

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