CTSD-ADV-1466
Revision: Basic

Advanced Exploration Systems (AES) Logistics Reduction Project: Crew Clothing Care Process Development

Crew and Thermal Systems Division

August 10, 2017
Revision: BASIC

Verify that this is the correct version before use.

Crew and Thermal Systems Division
Engineering Directorate
Lyndon B. Johnson Space Center
Houston, Texas

Crew Clothing Care Process Development

Concurrence Sheet

Prepared by:	Morgan Demmler, Intern Design & Analysis Branch Crew and Thermal Systems Division	8/10/17 Date
Prepared by:	Nickolas Whitehead, Intern Design & Analysis Branch Crew and Thermal Systems Division	8/10/17 Date
Prepared by and Edited by:	Darwin Poritz, Statistician Design & Analysis Branch Crew and Thermal Systems Division	11/21/17 Date
Prepared by and Edited by:	Evelyne Orndoff, Mentor Design & Analysis Branch Crew and Thermal Systems Division	11/21/17 Date
Reviewed by:	Michael Ewert Design & Analysis Branch Crew and Thermal Systems Division	11/27/17 Date
Approved by:	Victoriano Z. Untalan, Chief Design & Analysis Branch Crew and Thermal Systems Division	11/28/17 Date

Change Record

Rev.	Date	Originators	Approvals	Description
Basic	8/10/2017	Morgan Demmler Nickolas Whitehead Darwin Poritz	Victoriano Untalan	Original

Table of Contents

Table of Tables

Table of Figures

1.0 INTRODUCTION

Clothing cleaning, odor removal, and sanitation are vital to a person's ability to feel comfortable and confident for everyday life. This is a challenge that must be addressed for NASA's long-duration human missions to deep space and first human mission to Mars. Since these missions could take anywhere from months to years, resources will be very limited. Currently, on the International Space Station, or ISS, crew members throw away clothing after it begins to become unwearable for the crew member wearing it, since no laundry protocol exists. One important cause for discarding clothing is odor buildup. Previous efforts have studied various fabrics which could result in extending garment length of wear. These studies have been summarized in [1]. However, the first human mission to Mars may not have enough resources to carry the amount of clothing for the crew members to use the clothing disposal protocol currently used by the ISS, even with the use of fabrics which result in extending garment length of wear. The research results in this report constitute a significant step toward the development of a clothes-cleaning system to allow crew members going to Mars to prolong considerably clothing length of wear. Recommendations for further research and development are presented below in section 1.2 and in section 8.0.

The typical laundry system on Earth is not a viable option to clean clothing in a space habitat. Water behaves quite differently in zero gravity. The hydrogen bonding between molecules creates a strong surface tension that keeps the water molecules clumped together in large blobs. This makes the water non-dispersible, making it difficult to soak a garment in water. A standard washing machine also consumes a lot of energy and produces a lot of waste water. This causes issues because energy and water are limited resources and the water must be filtered for reuse as much as possible. The water filtration system also gives rise to many questions about detergents.

The present study investigated odor reduction and elimination through the use of a water solution as a mist with detergent and through the use of ozone. Water mist moves through air in a manner similar to that of a gas, even though it is a suspension and not a gas. On a practical time scale, water mist will not clump into blobs of water in microgravity and therefore can be used to transport detergent to clothing in a contained space and hence to saturate clothing with detergent solution.

It is important to limit detergent use as much as possible and to choose a detergent that will be compatible with the spacecraft's water recovery system. For this reason, we picked 7th Generation Free and Clear laundry detergent for this study, as it is a benign detergent commercially available. We will go further into the research behind this later in this report.

One method of odor removal and sanitation that is already in use on Earth is ozonation. It is often used by nurseries for sanitation purposes and by dry cleaners for clothing which is too delicate for the chemicals used in traditional dry cleaning. It is also used to remove musty or smoky odors from furniture. Empirical findings have shown that such ozone treatments are more effective in the presence of high humidity (see section 4.0). A small amount of water is needed to provide such humidity. Since this method of "cleaning" uses minimal water and is relatively safe, it is a good candidate for cleaning clothes in space. The method of ozone generation used for this experiment was ultraviolet (UV) generation. UV ozone generation is an affordable, relatively simple, and safe method of ozone generation, unlike many of the other methods used today. UV ozone generation uses ambient air, which needs no treatment for filtration. UV lamps convert oxygen molecules into ozone molecules, and then the ozone decays back to oxygen with a relatively short half-life. The levels of ozone generation produced by UV light is sufficient for odor removal.

In this study, we observed the effects of different concentrations of detergent with and without ozone to remove odor from t-shirts used during exercise. The fabrics of these shirts were categorized into two groups: hydrophobic (polyester and modacrylic) and hydrophilic (cotton and Merino wool). Hydrophilic fabrics are made from natural and more complex fibers. Hydrophobic fabrics are made from synthetic fibers. For this reason, hydrophilic fabrics absorb much more water than hydrophobic fabrics. Since water consumption is of primary concern, hydrophobic fabrics would seem to be a better choice. However, hydrophobic fabrics are considerably more flammable than hydrophilic fabrics. This means that hydrophobic fabrics would probably need to be treated for flame retardancy before use in a spacecraft. Aboard the ISS, polyester clothing is used by astronauts only for exercise purposes. For these reasons, hydrophilic fabrics are used for everyday wear.

1.1 Summary of Findings

A solution with a higher detergent concentration produces a statistically significantly greater odor acceptance than does a lower concentration.

Applying detergent solution as a mist sufficient to achieve saturation can be effective in eliminating odors from athletically soiled shirts either with or without exposure to ozone. Several cycles of application of detergent solution as a mist and of ozone and mechanical removal of soiled solution will be necessary for thorough cleaning. This is especially true for synthetic fabrics. One or more applications and removal of water mist will be necessary to remove residual ozone. Such rinse cycles will also likely be necessary to remove residual detergent.

1.2 Summary of Recommendations

Follow-on studies are recommended to confirm and advance the findings of the screening study presented here. The follow-on studies should use the more effective ZONOsanitech ozonating chamber located in the Advanced Materials Laboratory in the Crew and Thermal Systems Division. This chamber also provides control and recording of ozone concentrations and relative humidity, as well as providing the high humidity needed for effective sanitizing and providing fast catalytic ozone destruction.

The fast catalytic ozone destruction capability of the ZONOsanitech ozonating chamber will likely aid in the reduction or elimination of any ozone retained in garment fabric. Additionally, one or more applications and removal of water mist can be included in the process to remove residual ozone.

Several cycles of application of detergent solution as a mist and of ozone and mechanical removal of soiled solution will be necessary for thorough cleaning. This is especially true for synthetic fabrics. One or more applications and removal of water mist will likely be necessary to remove residual detergent.

For the harder-to-clean synthetic fabrics, a detergent formulated for synthetic fabrics, such as Win, should be included as well as additional cleaning cycles and one or more rinse cycles.

Another aspect to investigate further is wear life. Further studies should determine the optimal duration of wear before washing, as an overly soiled shirt can retain odors beyond the point of removal. The total lifetime of a shirt after repeated wear and washing should also be determined in order to estimate the number of shirts per person required for a Mars mission. A rinse cycle may need to be included in the washing protocol in order to prevent any dermal irritation from detergent otherwise retained in the clothing.

2.0 TEST DESCRIPTIONS AND PROCEDURES

2.1 Effect of Ozone on Detergent

It was desirable to determine if the ozone treatment produced any effect on detergent that had already been applied to the garments. Gas chromatography mass spectroscopy (GC-MS) was used to determine any such effects.

Soiled coupons for modacrylic, polyester, cotton, and Merino wool were obtained from shirts provided by an exercise participant. For just this particular analysis, the participant who wore the shirt that provided the coupons did not wear deodorant or antiperspirant, so that chemicals in these products would not interfere with the results from gas chromatography and mass spectrometry. Clean coupons were obtained from a previous study as controls. A small portion of each coupon was used to conduct each test. Since GC-MS requires the sample to be in a gaseous state, a pyrolyzer was used to pyrolyze the sample. Helium gas is used to transport the sample to the gas chromatograph.

Gas chromatography mass spectroscopy (GC-MS) of sample fabric swatches treated with detergent solution indicates that the ozone exposure in this study does not degrade the detergent 7th Generation Free & Clear. This implies that the detergent should remain effective even when ozone is applied after detergent is applied.

2.2 Preliminary Odor Detection Study

A preliminary study was designed in order to test some initial ideas concerning the importance of certain treatment combinations and to refine experimental techniques and test procedures. The treatment combinations included the detergent and water mist saturation.

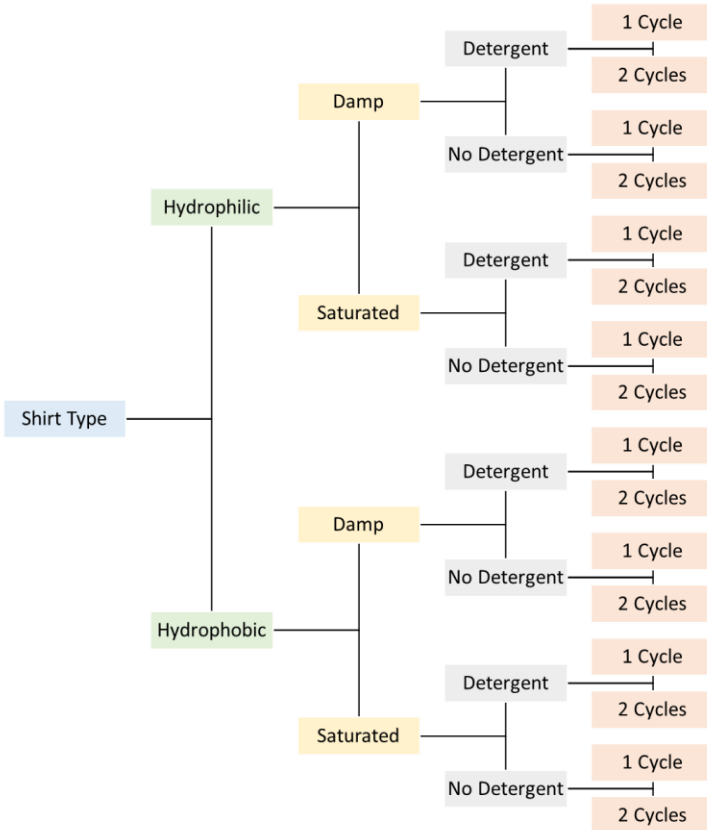
In this preliminary study, a group of participants wore exercise t-shirts of four fabric types: Merino wool, cotton, polyester, and modacrylic. These dirty shirts were treated using various methods in an attempt to remove odor. A panel of four persons then sniffed the treated shirts for the presence of any odors. Each panelist assigned an ordinal ranking to each shirt according to the interpretation given in **Table 1**.

Table 1. Odor Rank Order for Preliminary Study Design

Rank Order	Interpretation
1	neutral
2	slight odor
3	definite odor

This study used a full factorial design, which is explained below, with the intension of variable reduction. The shirts were treated according to the following steps:

Figure 1. Preliminary Study Design



1. Equal numbers of hydrophilic fabric t-shirts (cotton or Merino wool) and hydrophobic fabric t-shirts (polyester or modacrylic) were distributed among exercise participants.
2. Each t-shirt was worn during exercise in order to achieve a normal level of soiling. After exercise, each wearer hung his shirt up to dry
3. Upon return of each shirt to the laboratory, the shirts were saturated with water by immersing them in a basin.
4. All the shirts were then spun in a hand-operated spinner for water extraction and agitation.
5. The shirts were then divided into two groups, Group A and Group B, with equal numbers of shirts for each fabric type (hydrophilic or hydrophobic). Group A is labeled Damp in **Figure 1**, and Group B is labeled Saturated in **Figure 1**.
6. Group A was further divided into two groups, Group A1 and Group A2, with equal numbers of shirts for each fabric type (hydrophilic or hydrophobic).
   a. Group A1 was sprayed with a 13% mixture of detergent by volume until damp using a bottle sprayer and then placed in a Whirlpool[1] washing machine for 5 minutes on a low spin and drain cycle and then hung up to dry.
   b. Group A2 was not treated with detergent, but directly placed in a Whirlpool[2] washing machine for 5 minutes on a low spin and drain cycle and then hung up to dry.

[1] Whirlpool Duet, model WFW94HEAC0, a front-loading washer, Drain & Spin mode, Slow setting.
[2] ibid.

7. Group B was further divided into two groups, Group B1 and Group B2, with equal numbers of shirts for each fabric type (hydrophilic or hydrophobic).
    a. Group B1 was sprayed with a 13% mixture of detergent by volume until damp using a bottle sprayer and then hung up to dry.
    b. Group B2 was hung up to dry without being treated with any detergent
8. Each group A1, A2, B1, and B2, was further divided into two groups, A1s, A1c, A2s, A2c, B1s, B1c, B2s, and B2c, with equal numbers of shirts for each fabric type (hydrophilic or hydrophobic).
    a. Shirts in groups A1s, A2s, B1s, and B2s were assessed for odor by the sniff panelists according to the ordinal scale in **Table 1**.
    b. Shirts in groups A1c, A2c, B1c, and B2c were assessed for odor by the sniff panelists according to the ordinal scale in **Table 1**. These shirts were then treated with a second cycle according to steps 3, 4, 6a, 6b, 7a, and 7b, and then were assessed for odor by the sniff panelists according to the ordinal scale in **Table 1**.

Due to the small sample size, no formal statistical conclusions could be drawn from the data. Instead, conclusions were made by an informal review and assessment of the data. This preliminary study resulted in the conclusions that detergent was necessary for odor removal, that the damp condition was not necessary, and that all four types of shirt fabric should be evaluated individually rather than just categorized into two different categories: hydrophilic and hydrophobic. This conclusion directly informed the design of the following screening study described in section 2.4.

2.3 Water Saturation Weight Study

In the course of the preliminary odor detection study, 23 shirts were weighed after step 4 in section 2.1. The dry weight of each shirt had been taken before being worn for exercise, and this dry weight was subtracted from the weight after step 4 to determine the weight of water absorbed by the shirt. These weights in grams are displayed below in **Table 4**. The statistical analysis is described below in section 6.1. The water weight as a percentage of shirt weight taken up by Merino wool and modacrylic shirts is about 150% while the percentage for cotton and polyester shirts is about 250%.

2.4 Screening Study Design

Following the preliminary study, a follow-on study was designed to identify which treatments are significant and which are not. A full factorial design with most treatment factors at two levels was used for the experiment. This is the usual approach for designs to assess, or screen, factors for their relevance.

For this screening study, a group of participants wore exercise t-shirts of four fabric types: Merino wool, cotton, polyester, and modacrylic. These dirty shirts were treated using various methods in an attempt to remove odor. A panel of three persons then sniffed the treated shirts for the presence of any odors. Each panelist assigned an ordinal ranking to each shirt according to the interpretation given in **Table 2**.

Table 2. Odor Rank Order for Screening Study Design

Rank Order	Interpretation
1	no detectable odor
2	slight odor
3	definite odor

In addition, each panelist assessed whether each shirt was or was not objectionable for further wear according to the interpretation given in **Table 3**.

Table 3. Objection to Further Wear for Shirt

Objectionable	Interpretation
no	not objectionable
yes	objectionable

This study used a full factorial design, which is explained below. The intention of using such a screening design is to identify factors (controlled variables) that do not produce significant effects and thus can be eliminated from future studies. The factors included detergent concentrations, the presence or absence of ozone, and the number of cleaning cycles (**Figure 2**).

The original plan for ozonation was to use the ZONOsanitech ozonating chamber located in the Advanced Materials Laboratory in the Crew and Thermal Systems Division. However, this chamber was not operational at the time of the present study. Therefore, a portable ozone generator was used, the UV Pro 550 Commercial UV Ozone Generator, Crystal Products & Services (now Crystal Air www.ozone.ca). This portable ozone generator is capable of producing only a low level of ozone concentration, typically no more than 3 parts per million. This compares to the 20 parts per million that the ZONOsanitech ozonating chamber can produce. A longer ozone exposure time of 45 minutes as used, as opposed to the recommended time for the ZONOsanitech ozonating chamber of 20 minutes. This strategy is effective, since the effect of ozone is cumulative over time.

The use of the portable ozone generator contained in a polyurethane bag (**Figure 3**) did not provide a regulated concentration of ozone and a regulated relative humidity, as would have been provided by the ZONOsanitech ozonating chamber. The ozone production of the portable ozone generator is variable over time. Moreover, accuracy the electro-chemical meters used to monitor the ozone concentration can also vary. For these reasons, the set-up in **Figure 3** was monitored to assure that an adequate ozone concentration was attained and maintained, but the ozone levels were not recorded.

The shirts were treated according to the following steps:

1. Equal numbers Merino wool, cotton, polyester, and modacrylic t-shirts were distributed among exercise participants. The Merino wool and cotton shirts are hydrophilic, and the polyester and modacrylic shirts are hydrophobic.
2. Each t-shirt was worn during exercise in order to achieve a normal level of soiling. After exercise, each wearer hung his shirt up to dry
3. The shirts were then divided into two groups, Group A and Group B, with equal numbers of shirts for each fabric. Group A is labeled Detergent Concentration 1 in **Figure 2**, and Group B is labeled Detergent Concentration 2 in **Figure 2**.
4. Upon return of each shirt to the laboratory, the shirts were sprayed, using a motorized chemical sprayer[3], to dispense one of two concentrations of detergent in water to saturate the shirt (7.4% by volume for group A and 13% by volume for group B). The cotton and Merino wool shirts were

[3] Ryobi 18 Volt Chemical Sprayer, model P2800.

treated with 500 mL of detergent solution, and the modacrylic and polyester shirts were treated with 250 mL of detergent solution.

5. Each shirt was then placed in a Whirlpool[4] washing machine for 5 minutes on a low spin and drain cycle for water extraction and agitation.
6. Group A was further divided into two groups, Group A1 and Group A2, with equal numbers of shirts for each fabric.
    a. Each shirt in group A1 was immediately put into the ozonation bag (**Figure 3**) after the spin cycle. The shirt was then ozonated for 45 minutes, using a UV ozone generator[5] in a bag made of polyurethane, then removed and laid on a drying rack.
    b. Each shirt in group A2 was not ozonated and was laid out to dry on a drying rack.
7. Group B was further divided into two groups, Group B1 and Group B2, with equal numbers of shirts for each fabric.
    a. Each shirt in group B1 was immediately put into the ozonation bag (**Figure 3**) after the spin cycle. The shirt was then ozonated for 45 minutes, using a UV ozone generator[6] in a bag made of polyurethane, then removed and laid on the drying rack.
    b. Each shirt in group B2 was not ozonated and was laid out to dry on a drying rack.
8. Each group A1, A2, B1, and B2, was further divided into two groups, A1s, A1c, A2s, A2c, B1s, B1c, B2s, and B2c, with equal numbers of shirts for each fabric.
    a. Shirts in groups A1s, A2s, B1s, and B2s were assessed for odor by the sniff panelists according to the ordinal scale in **Table 2** and according to the assessment in **Table 3**.
    b. Shirts in groups A1c, A2c, B1c, and B2c were assessed for odor by the sniff panelists according to the ordinal scale in **Table 2** and according to the assessment in **Table 3**. These shirts were then treated with a second cycle according to steps 4, 5, 6a, 6b, 7a, and 7b, and then were assessed for odor by the sniff panelists according to the ordinal scale in **Table 2** and according to the assessment in **Table 3**.

[4] op. cit.
[5] Crystal Products & Services (now Crystal Air www.ozone.ca), UV Pro 550 Commercial UV Ozone Generator.
[6] ibid.

Figure 2. Screening Study Design

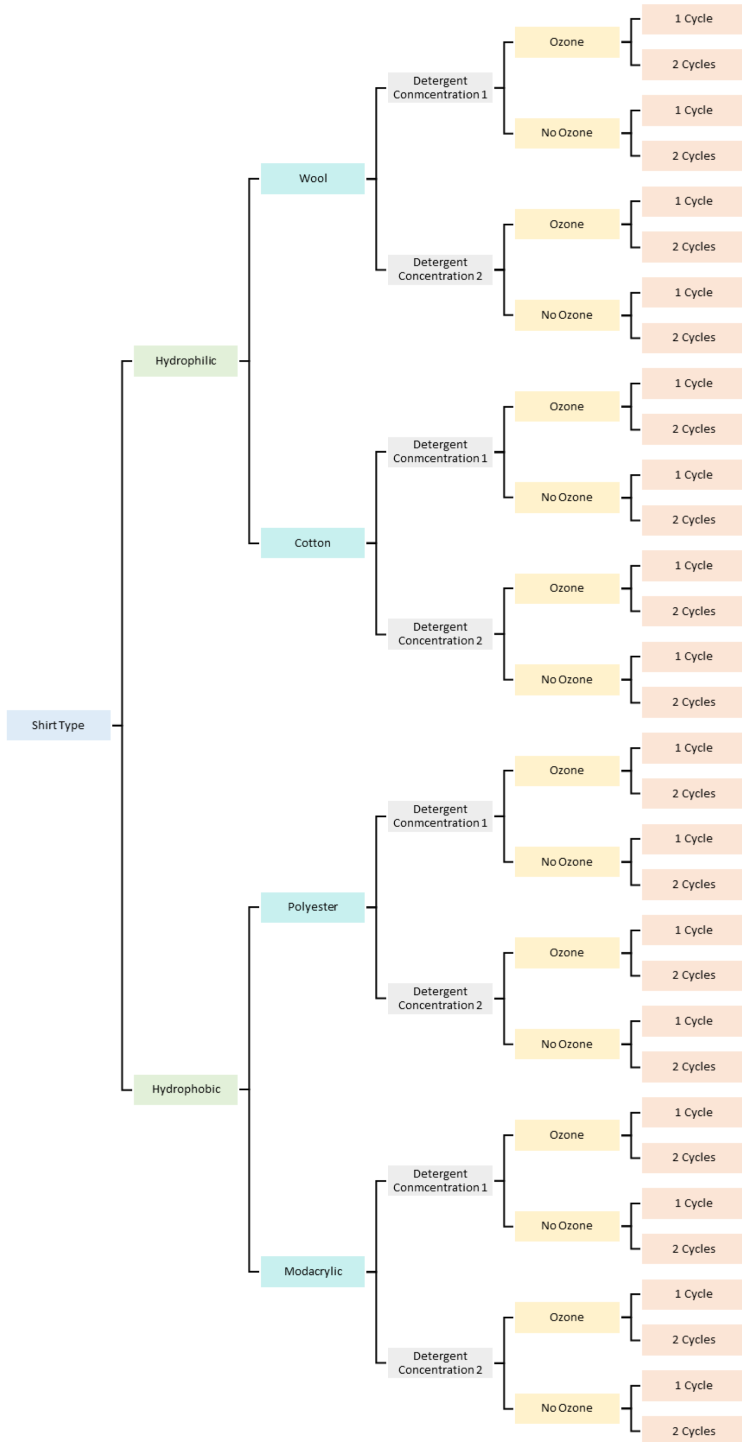


Figure 3. Ozonation Bag with Clothing, Generator, and Meters

3.0 DETERGENT CHEMISTRY

Detergents are defined as cleaning agents which interact with soiling agents to make the latter more soluble in water [2]. Detergents contain a variety of chemicals in the following categories: alkalis (bases), antimicrobial agents, anti-re-deposition agents, bleaches, colorants, corrosion inhibitors, enzymes, fabric softening agents, fluorescent whitening agents, fragrances, hydrotropes, opacifiers, preservatives, processing aids, solvents, suds suppressors (anti-foaming agents), and surfactants [2].

Surfactants, the most important component in detergents, alter the surface tension of water and allow for easier wetting of the surface being cleaned. Unlike soaps, which are made from fatty acids, the surfactants in detergents are derived from petroleum, oils, and fats. In addition, surfactants form micelles around the soiling agents, which allow the soiling agents to be carried away in the aqueous environment. Surfactants also decrease the surface tension in water allowing for easier wetting of the fabric materials. Anti-re-deposition agents are used to prevent the soiling agents from resettling on clothes after the soiling agents have been removed by the surfactants. Since detergents have been shown to be more efficient at higher pH values, a base such as sodium hydroxide may be included in the detergent [2]. However, the high pH can affect the solubility of the surfactant. Therefore, hydrotropes can be added to improve the solubility of the surfactants due to the small molecular size and amphiphilic nature of hydrotropes. Hard water can reduce the efficiency of surfactants due to ions such as calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), and potentially iron ions (Fe^{2+}) and manganese ions (Mn^{2+}). Water softeners, sometimes referred to as chelating agents or sequestration agents, bind with these ions to prevent the ions from reacting with surfactants and other components of the detergent. Modern detergents can contain enzymes such as proteases, amylases, lipases, and/or mannanases for removing protein, starch, oil, and natural gum-based stains (e.g., guar gum), respectively. Enzyme stabilizers such as glycerin (glycerol) are used to protect the enzyme and to prevent the enzyme from becoming denatured by other chemicals. Detergents often include preservatives to extend the shelf life. Some preservatives can act as antimicrobial agents or antioxidants. Colorants, fragrances, fabric softening agents, and fluorescent whitening agents are used in detergents to improve the appearance or smell of fabrics. Bleaches can be included in this category because they can whiten clothes. Moreover, bleaches also disinfect and help remove stains. These materials do not alter the efficiency of the surfactant. Processing aids and opacifiers affect the physical properties, such as opacity and viscosity, of the detergent. Processing aids can also be chemicals that are used to make other chemicals used in the detergent. Residuals of these processing aids may remain in detergent.

Seventh Generation Free & Clear, the detergent used in this study, does not contain fragrances and dyes. According to the safety data sheet, Seventh Generation Free & Clear contains water, laureth-6, sodium lauryl sulfate, sodium citrate, glycerin, sodium chloride, oleic acid, sodium hydroxide, calcium chloride, citric acid, protease, amylase, mannanase, benzisothiazolinone, and methylisothiazolinone. This detergent was suitable for the present study because the detergent did not contain whitening agents, colorants, and opacifiers. Water softeners were required because tap water was used in this experiment.

4.0 OZONE CHEMISTRY

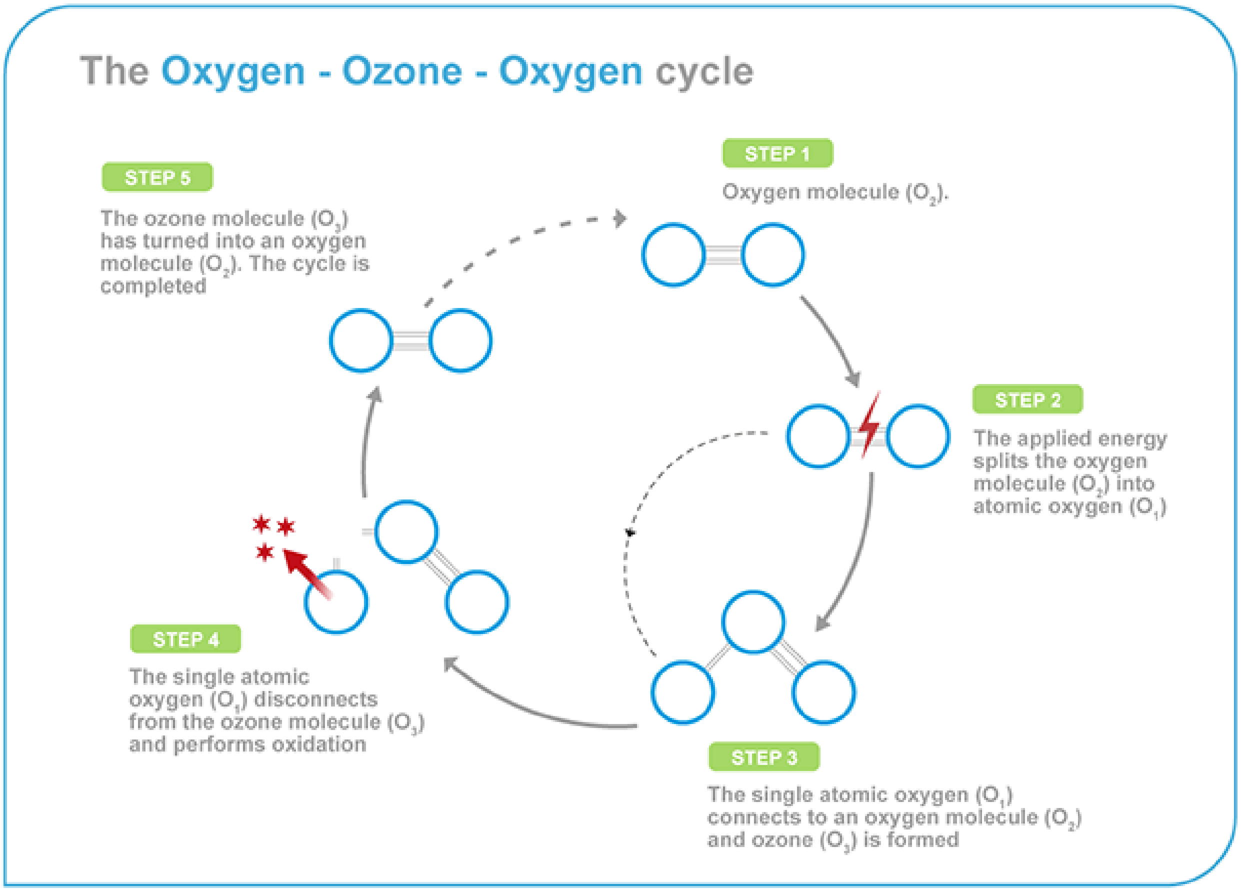
Ozone (O_3) is a strong oxidative gas that occurs naturally in the stratosphere [3]. Ultraviolet light photolyzes diatomic oxygen yielding monatomic oxygen (**Figure 4**), optimally at 172 nanometers [3], and generally between 160 and 240 nanometers [4]. The monatomic oxygen reacts with another diatomic oxygen to form ozone. Other wavelengths of ultraviolet light can photolyze ozone yielding diatomic oxygen and monatomic oxygen, optimally at 254 nanometers ([4] , [5]), and generally between 240 and 315 nanometers [4]. The free monatomic oxygen can bond to another monatomic oxygen producing diatomic oxygen. Since ozone is a very strong oxidizer and decomposes to diatomic oxygen, ozone is used as an antimicrobial agent for food products, food transport and storage containers, and medical equipment [6]. In addition, ozone is used to remove odors from furniture, rooms, and fabrics that cannot withstand the chemicals used in dry cleaning. Ozone is also used in water treatment to degrade pollutants [7].

Ozone is involved in direct oxidation reactions and in indirect oxidation reactions. In the direct oxidation reaction, ozone directly oxidizes other reactants. Ozone primarily reacts at the location of double bonds and triple bonds while hydroxyl radicals are not as selective. However, in indirect oxidation reactions, ozone interacts with other reactants to form radicals such as hydroxyl radicals. These newly formed radicals directly oxidize other molecules. Indirect oxidation is the primary process for water sanitation [8].

A summary of studies from Ozone Solutions [9] indicates that more than an 80% reduction in a mix of bacteria on environmental surfaces was obtained from dry gaseous ozone at 1 part per million after 60 minutes and that almost complete elimination of Pseudomonas aeruginosa on stainless steel plates was obtained from gaseous ozone at 0.3 parts per million at 85% to 95% relative humidity after 120 minutes. A study [10] of gaseous ozone at 0.5 parts per million in an imperfectly sealed conference room showed 90% reduction in airborne bacteria after 30 minutes. Studies of ozone exposure at 20 parts per million at high humidity for 20 to 30 minutes in a sealed chamber showed 99.9% reduction in pathogenic bacteria [11] and pathogenic viruses [12].

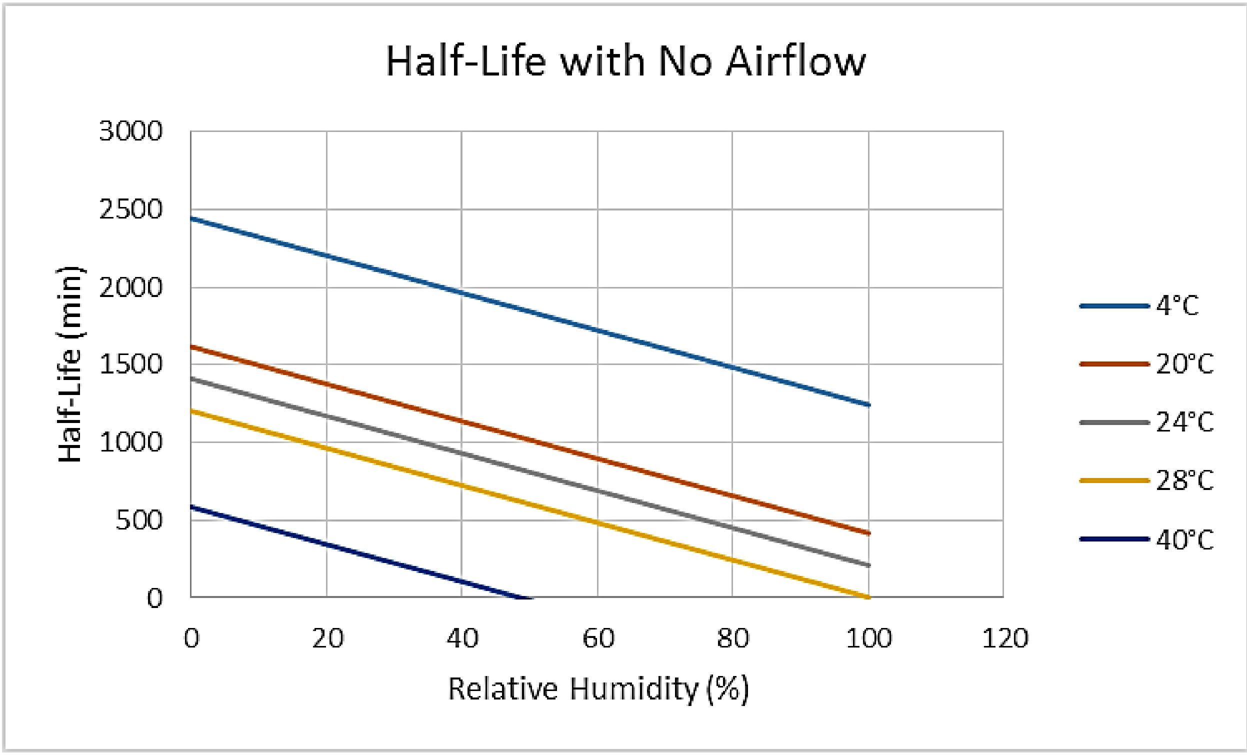
Ozone is an unstable gas with a relatively short half-life dependent on temperature and humidity (**Figure 5**). Moreover, the destruction of ozone to molecular oxygen can be accelerated by means of a manganese dioxide catalyst [13]. The simple on-site generation and destruction of ozone makes it a logistically convenient material.

Figure 4. Oxygen-Ozone-Oxygen Cycle[7]



[7] https://www.azom.com/article.aspx?ArticleID=10718

Figure 5. Ozone Half-Life by Humidity and Temperature



5.0 WATER SATURATION

A sufficient amount of water was used as a solvent for each garment in order to dissolve or suspend salts and other compounds or particulates. This amount of water was defined *a priori* as that required to saturate the garment. Measurements were taken on 23 garments for dry weight and saturated weight. Water weight was determined by subtracting dry weight from saturated weight, and percent water weight was calculated as 100 times the ratio of water weight to dry weight. The data are displayed in **Table 4**.

Statistical analysis of the data is presented in section 6.1

Table 4. Saturated Garment Data

Obs	Fabric	Size	Dry_Weight_g	Saturated_Weight_g	Water_Weight_g	Pct_Water_Weight
1	Modacrylic	XXL	198	510	312	157.576
2	Modacrylic	L	166	375	209	125.904
3	Modacrylic	XL	181	462	281	155.249
4	Cotton	XXL	212	723	511	241.038
5	Cotton	L	158	522	364	230.380
6	Cotton	XL	200	630	430	215.000
7	Polyester	XXL	174	535	361	207.471
8	Polyester	L	162	509	347	214.198
9	Polyester	XL	173	610	437	252.601
10	Merino Wool	XXL	207	492	285	137.681
11	Merino Wool	M	154	372	218	141.558
12	Merino Wool	L	168	382	214	127.381
13	Merino Wool	XL	177	415	238	134.463
14	Modacrylic	XXL	202	433	231	114.356
15	Modacrylic	L	184	484	300	163.043
16	Modacrylic	XL	184	514	330	179.348
17	Cotton	L	165	563	398	241.212
18	Cotton	XL	164	602	438	267.073
19	Polyester	XXL	178	598	420	235.955
20	Polyester	L	140	522	382	272.857
21	Polyester	XL	167	655	488	292.216
22	Merino Wool	L	179	504	325	181.564
23	Merino Wool	XL	186	404	218	117.204

6.0 STATISTICAL ANALYSIS

All statistical analyses and tabulations were performed with SAS® software [14].

6.1 Determination of Minimum Water Saturation

Water weight and percent water weight were regressed against fabric and garment size. Only fabric was a significant explanatory variable. The sample size for the quantitative observation of water weight was considered adequate for a 5% significance level (95% confidence limits).

For the regression of water weight against fabric, the additive residual error in the regression model was assumed to be normally distributed. The regression was performed with the SAS procedure GLM. The following normal probability quantile plot in **Figure 6** shows that the residuals (the estimated errors) from the regression are independently and identically normally distributed. Normal independently and identically distributed residuals lie on a straight line. A Kolmogorov- Smirnov test for the normality of the residuals is displayed in **Table 5**. The test value is consistent with hypothesis of normality at the 5% significance level, since the significance value is greater than 0.05.

Figure 6. Normal Quantile Plot of Residuals for Water Weight vs Fabric

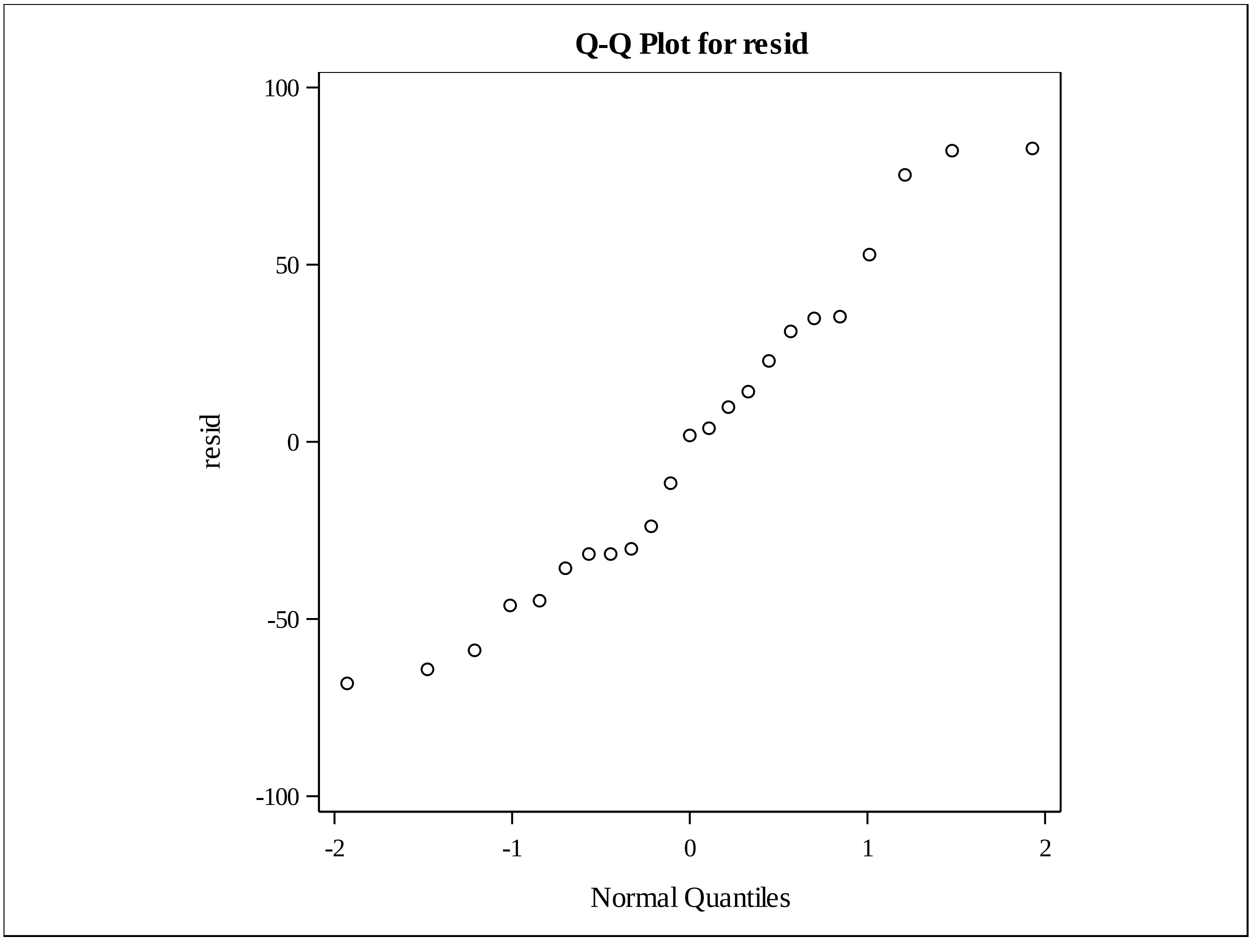


Table 5. Kolmogorov-Smirnov Test of Residuals for Water Weight vs Fabric

Tests for Normality				
Test	**Statistic**		**Significance Value**	
Kolmogorov-Smirnov	**D**	0.1332	**Pr > D**	>0.1500

Table 6 displays the summary analysis of variance for the regression of water weight against fabric and shows that the model explains a significant proportion of the variation in the data. **Table 7** shows that this proportion (R^2) is a respectable 74%.

Table 6. Summary Analysis of Variance for Water Weight vs Fabric

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model (Fabric)	3	137249.6783	45749.8928	18.26	<.0001
Error	19	47607.8000	2505.6737		
Corrected Total	22	184857.4783			

Table 7. Goodness of Fit for Water Weight vs Fabric

R-Square	Coeff Var	Root MSE	Water_Weight_g Mean
0.742462	14.88050	50.05670	336.3913

Table 8 displays the average water weight taken up by each fabric along with 95% confidence limits for these averages. **Table 9** displays the significance values for the differences of average water weights for each fabric. Cotton and polyester are similar in the amount of water taken up, and likewise Merino wool and modacrylic are similar in the uptake of water. The water uptake by cotton and polyester, on the one hand, is significantly greater than the uptake, on the other hand, by Merino wool and modacrylic.

Table 8. Estimates of Water Weight by Fabric

Fabric	Water_Weight_g LSMEAN	95% Confidence Limits		LSMEAN Number i/j
Cotton	428.200000	381.345482	475.054518	1
Merino Wool	249.666667	206.894539	292.438794	2
Modacrylic	277.166667	234.394539	319.938794	3
Polyester	405.833333	363.061206	448.605461	4

Table 9. Statistical Significance of Differences of Estimated Water Weight by Fabric

Least Squares Means for effect Fabric Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: Water_Weight_g				
i/j	**1**	**2**	**3**	**4**
1		<.0001	<.0001	0.4696
2	<.0001		0.3533	<.0001
3	<.0001	0.3533		0.0003
4	0.4696	<.0001	0.0003	

In order to generalize the water requirement further, it is useful to look at the water required as a percent of garment weight and therefore not dependent on the actual garment weight.

For the regression of percent water weight against fabric, the additive residual error in the regression model was assumed to be normally distributed. The regression was performed with the SAS procedure GLM. The following normal probability quantile plot in **Figure 7** shows that the residuals (the estimated errors) from the regression are independently and identically normally distributed. Normal independently and identically distributed residuals lie on a straight line. A Kolmogorov- Smirnov test for the normality of the residuals is displayed in **Table 10**. The test value is consistent with hypothesis of normality at the 5% significance level, since the significance value is greater than 0.05.

Figure 7. Normal Quantile Plot of Residuals for Water Percent Weight vs Fabric

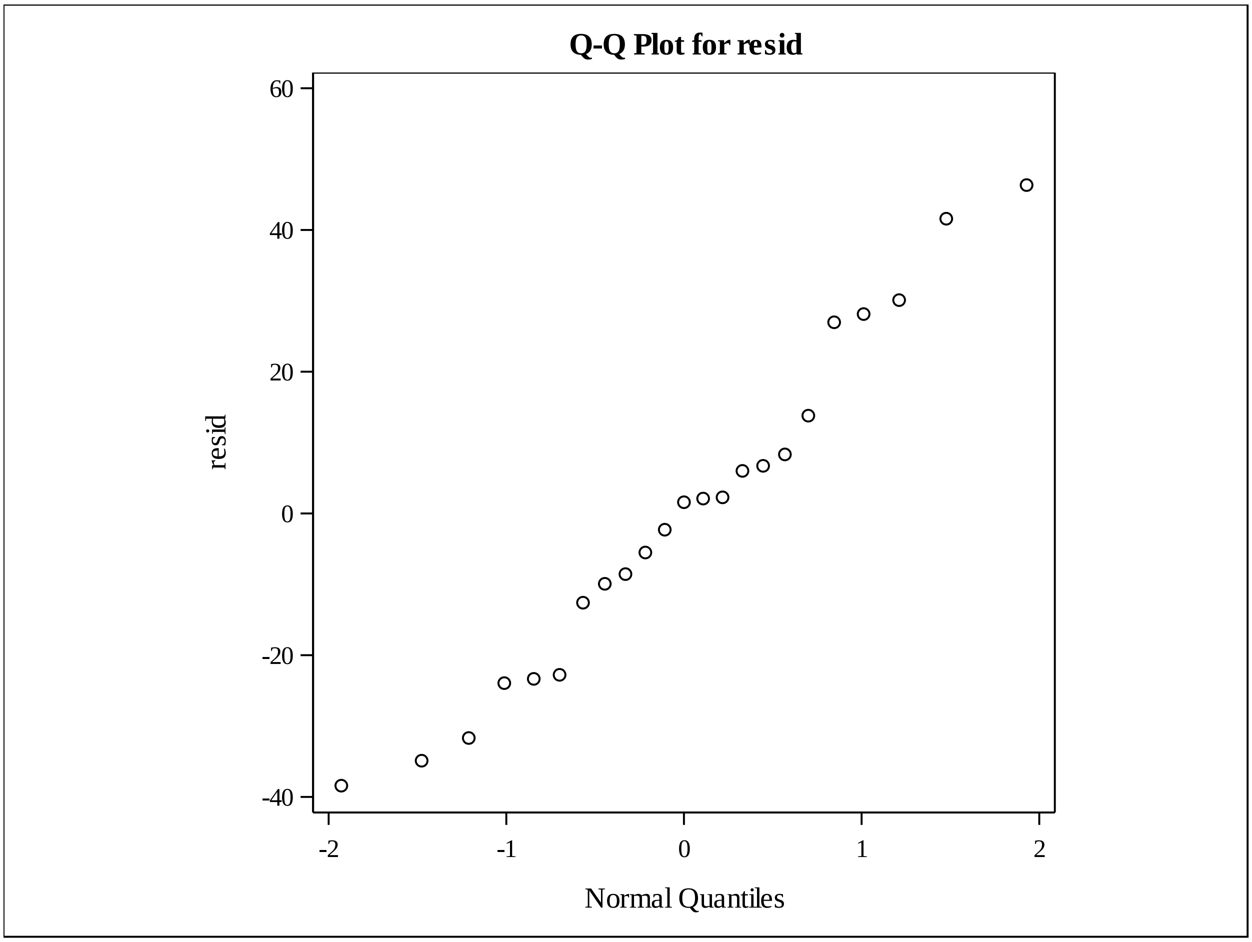


Table 10. Kolmogorov-Smirnov Test of Residuals for Percent Water Weight vs Fabric

Tests for Normality				
Test	**Statistic**		**Significance Value**	
Kolmogorov-Smirnov	**D**	0.101731	**Pr > D**	>0.1500

Table 11 displays the summary analysis of variance for the regression of water weight against fabric and shows that the model explains a significant proportion of the variation in the data. **Table 12** shows that this proportion (R^2) is a respectable 82%.

Table 11. Summary Analysis of Variance for Percent Water Weight vs Fabric

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model (Fabric)	3	55639.16964	18546.38988	28.52	<.0001
Error	19	12353.86277	650.20330		
Corrected Total	22	67993.03241			

Table 12. Goodness of Fit for Percent Water Weight vs Fabric

R-Square	Coeff Var	Root MSE	Water_Weight_g Mean
0.818307	13.31294	25.49908	191.5360

Table 13 displays the average percent water weight taken up by each fabric along with 95% confidence limits for these averages. **Table 14** displays the significance values for the differences of average percent water weights for each fabric. Cotton and polyester are similar in the percent of water taken up, and likewise Merino wool and modacrylic are similar in the uptake of percent water. The percent water uptake by cotton and polyester, on the one hand, is significantly greater than the percent uptake, on the other hand, by Merino wool and modacrylic.

Table 13. Estimates of Water Percent Weight by Fabric

Fabric	Pct_Water_Weight LSMEAN	95% Confidence Limits		LSMEAN Number i/j
Cotton	238.940555	215.072677	262.808433	1
Merino Wool	139.975396	118.187105	161.763688	2
Modacrylic	149.245955	127.457663	171.034247	3
Polyester	245.882953	224.094662	267.671245	4

Table 14. Statistical Significance of Differences of Estimated Percent Water Weight by Fabric

Least Squares Means for effect Fabric Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: Water_Weight_g				
i/j	**1**	**2**	**3**	**4**
1		<.0001	<.0001	0.6581
2	<.0001		0.5364	<.0001
3	<.0001	0.5364		<.0001
4	0.6581	<.0001	<.0001	

Overall, the minimum percent of fabric dry mass of water required by the tested garments is the largest amount required by any fabric, which is at least the 246% of fabric dry mass required by polyester.

6.2 Preference Analysis of the Screening Study

Logistic regression was used to analyze odor preference data from the screening study in order to determine the effectiveness of the cleaning processes with respect to eliminating odor. This is an appropriate analysis for ordered data such as preference responses. The odor rank order data described in **Table 2** were regressed against each of the main factors: fabric, detergent concentration, ozone application, and number of cycles. Due to the small sample size for the ordinal response, a 10% significance level (90% confidence limits) was used for drawing conclusions instead of the usual 5% significance level (95% confidence limits).

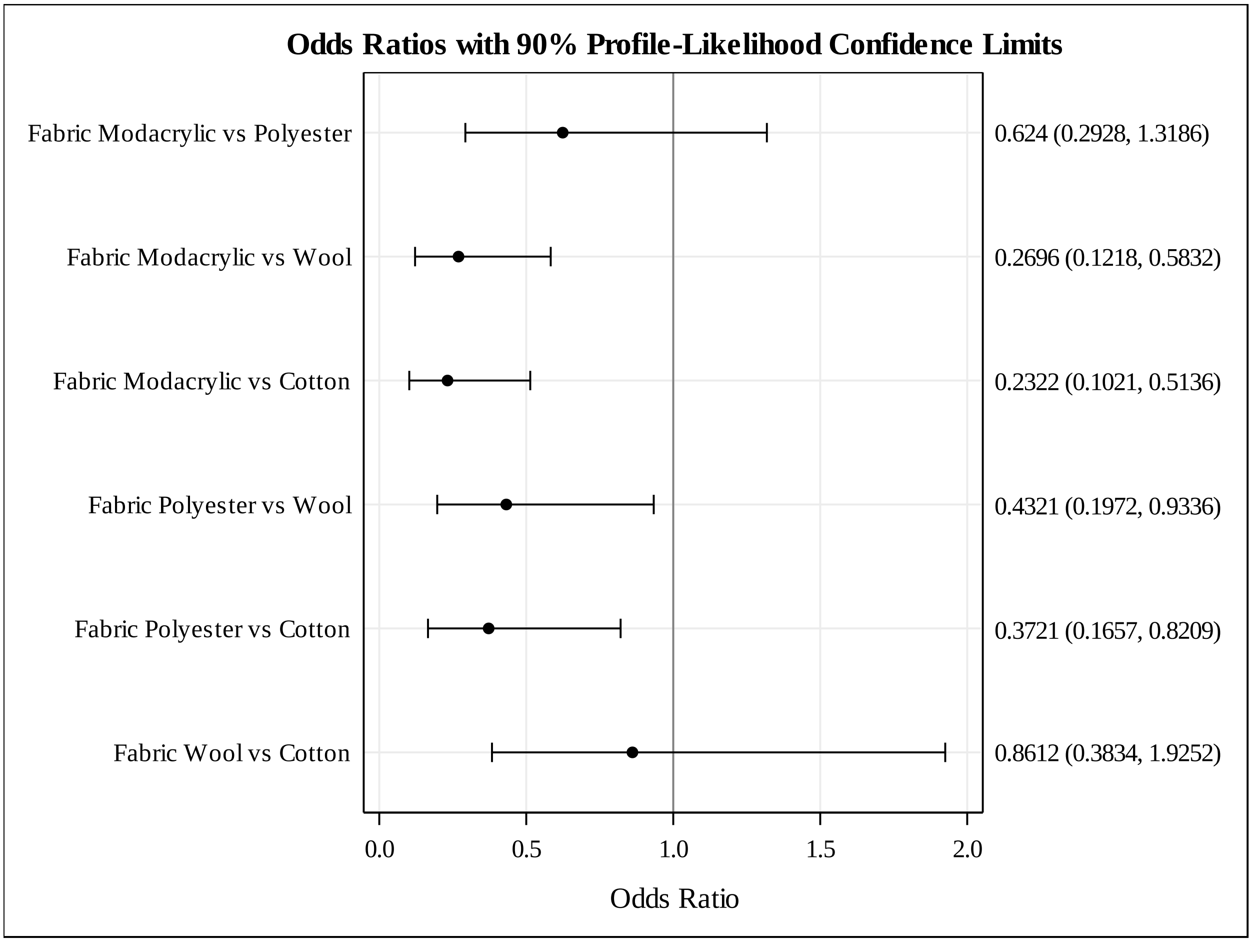
A similar logistic regression analysis of the objection data described in **Table 3** did not yield any additional information beyond that provided by the preference data. Therefore, the results from this latter analysis are not reported here.

The results of the logistic regression are given in terms of ratios of ratios of probabilities displayed in **Figure 8** and **Figure 9**, along with 90% confidence limits, shown within parentheses.

Some of the usual terminology used with logistic regression is not good and therefore is confusing. For each treatment, such as a particular fabric, the probability ratio is the ratio of the probability detecting less odor to the probability of the contrary, the probability of detecting more odor. Strictly speaking, such a ratio of probabilities is an odds ratio. However, the term odds ratio used in logistic regression does not mean this ratio of probabilities. The term odds ratio as used in logistic regression is the ratio of the probability ratio for one treatment to the probability ratio of another treatment. The apparent justification in logistic regression for using the term odds ratio in this way is that it is the ratio of odds ratios (ratios of probabilities for and against). In order to avoid further confusion, the expression logistic odds ratio will be used here for the term odds ratio as it is used in logistic regression.

The greater the logistic odds ratio, the greater is the preference in favor of no odor or minimal odor in one treatment compared to another treatment. From **Figure 8**, cotton and Merino wool have a greater odds of no odor or minimal odor than modacrylic and polyester. For example, the logistic odds ratio for modacrylic versus Merino wool is 0.2696. Therefore, the logistic odds ratio for Merino wool versus modacrylic is the reciprocal $1/0.2696 = 3.709$. A logistic odds ratio of 1 means that there is no difference between the two treatments. If the confidence interval for a logistic odds ratio contains 1, then there is no statistically significant difference between the two treatments at the given level of significance. Alternatively, if the confidence interval does not include 1, then there is a statistically significant difference between the two treatments at the given level of significance. Cotton and Merino wool have statistically significantly lower odors than do modacrylic and polyester. The odor perceptions for cotton and Merino wool are statistically equivalent. Likewise, the odor perceptions for modacrylic and polyester are statistically equivalent.

Figure 8. Logistic Odds Ratios for Fabrics



Logistic odds ratios for the other treatments, namely detergent concentration, ozone, and cycles, are displayed in **Figure 9**, along with 90% confidence limits, shown within parentheses.

In this screening study, 250 grams of detergent solution was inadvertently applied to Merino wool rather than the 500 grams indicated by the analysis of water saturation. Likewise, 500 grams of detergent solution was applied to polyester rather than the 250 grams indicated by the analysis of water saturation. On the other hand, 250 grams of detergent solution was applied to modacrylic and 500 grams to cotton in accordance with the analysis of water saturation. In order to elucidate any effects of this variation in the application of detergent solution, which is specific to each fabric, the treatments of detergent concentration, ozone, and cycles were also analyzed for each fabric. These results are displayed in **Figure 10**, **Figure 11**, and **Figure 12** and discussed further below.

A solution with a higher detergent concentration produces a statistically significantly greater odor acceptance than does a lower concentration. On the one hand, it may be assumed that 7^{th} Generation detergent is formulated primarily for cleaning cotton. On the other hand, it is known that cleaning synthetics such as modacrylic and polyester is more difficult than cleaning a natural fiber such as cotton. **Figure 10** shows better odor acceptance at higher detergent concentration for Merino wool and modacrylic and likely for polyester as well. This means that a higher detergent concentration is preferred because of the inclusion of Merino wool, modacrylic and polyester in the study. In further studies, it may be advisable to include a detergent such as Win which is specifically formulated for cleaning synthetic fabrics.

From **Figure 9**, the use of ozone seems statistically significantly to increase the perception of odor in the sense that not applying ozone is preferable. It was not anticipated in this study that fabrics would retain ozone any appreciable time after exposure. Ozone has a sharp and easily perceived odor, even in concentrations which are quite low. **Figure 11** indicates that cotton, Merino wool and polyester have a propensity to retain ozone. A garment rinsing step or other ozone elimination step was not included in this study. Such a finishing step in the process should remove any residual ozone from fabrics. It may very well be useful to include ozone in the cleaning process in order to kill micro-organisms and degrade large molecules for easier suspension in the detergent solution and subsequent removal. Further studies should include one or more rinsing steps and perhaps an ozone neutralization step as well.

From **Figure 9**, the number of cleaning cycles seems neither to increase nor to decrease the perception of odor. **Figure 12** indicates that modacrylic, and to some extent polyester as well, achieve greater odor acceptance with two cycles, which may be related to the greater difficulty in cleaning synthetic fabrics. The indication that one cycle is preferable to two cycles for cotton and Merino wool may be related to ozone retention by these fabrics.

Figure 9. Logistic Odds Ratios for All Treatments

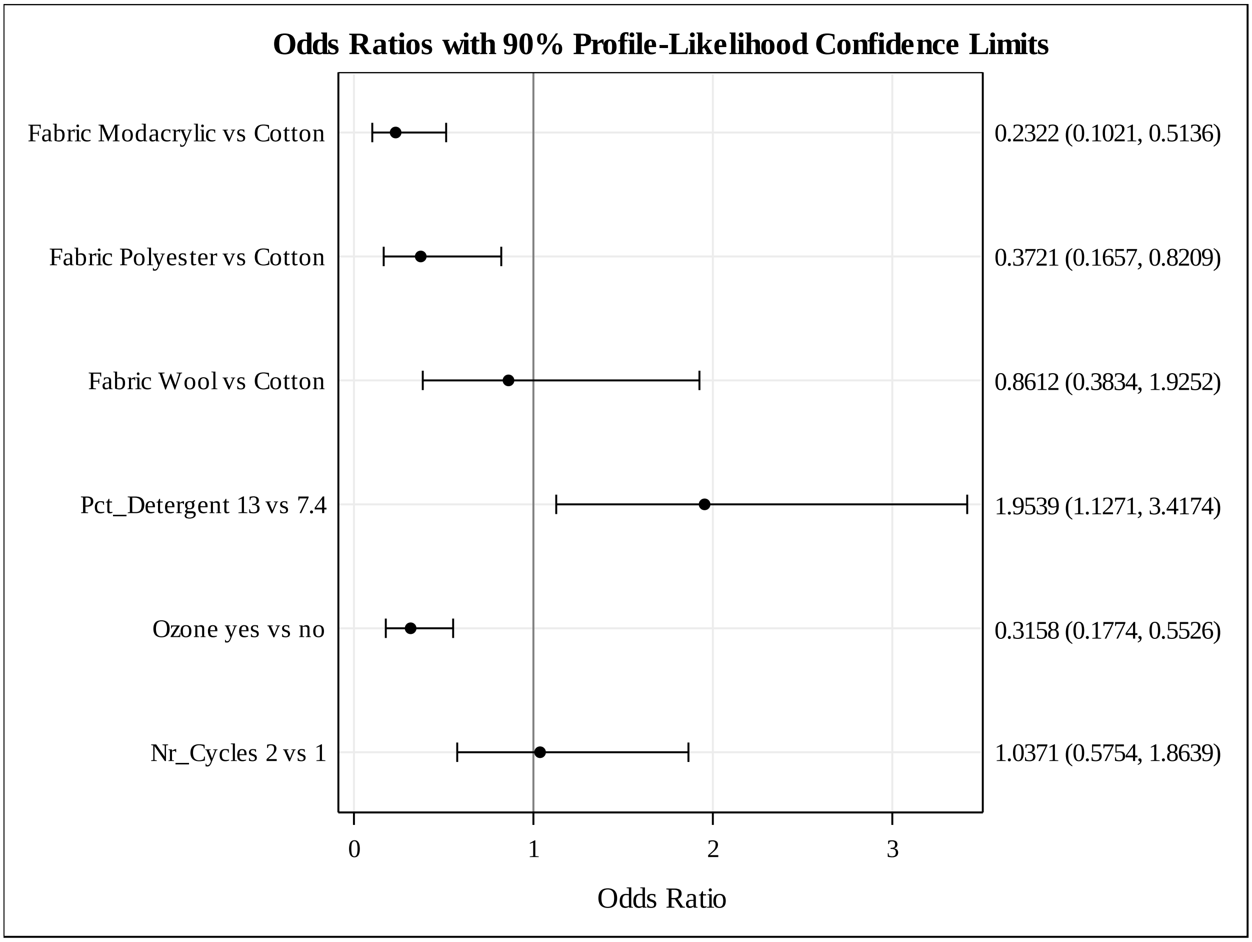


Figure 10. Logistic Odds Ratios for Detergent Concentration with Fabrics

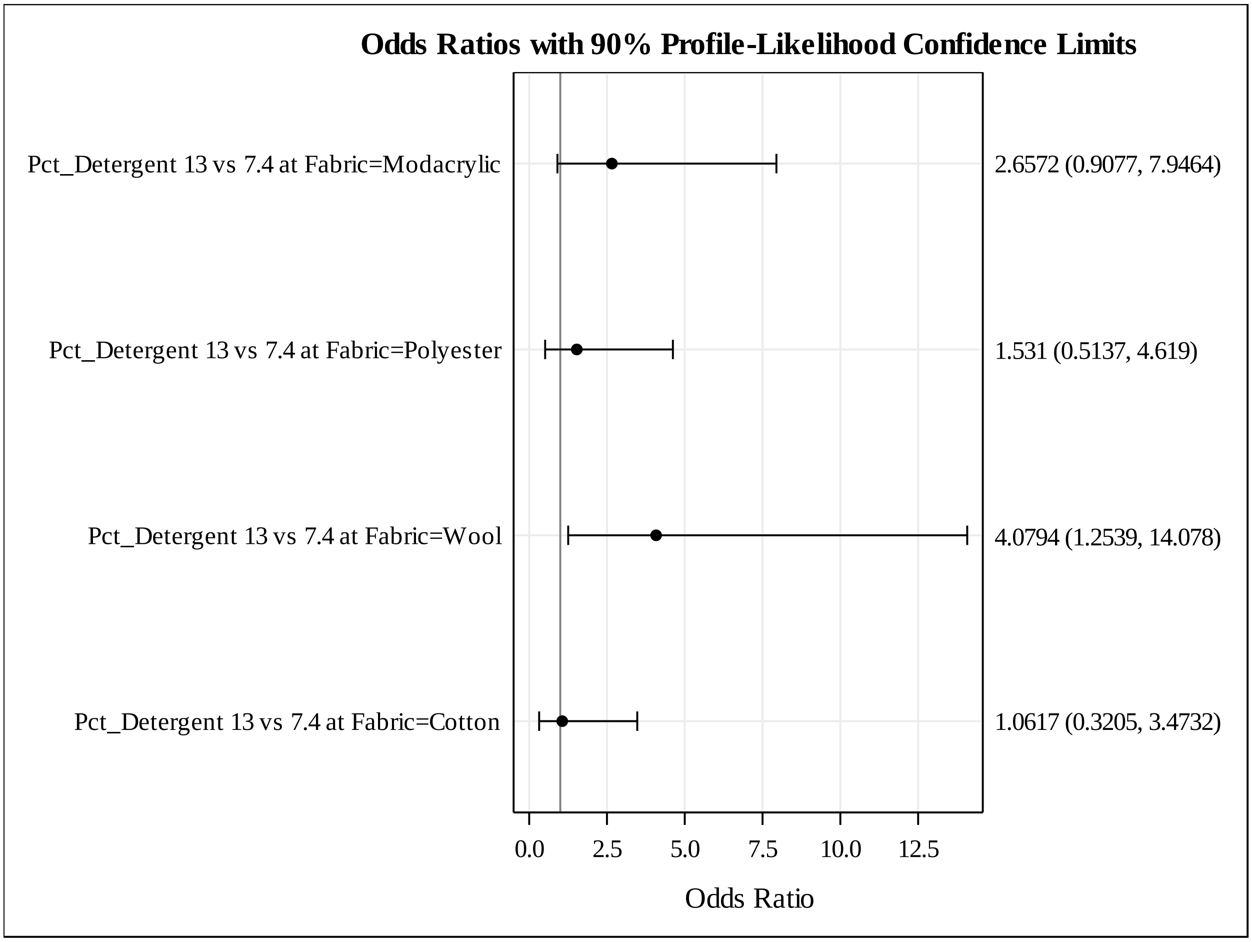


Figure 11. Logistic Odds Ratios for Ozone with Fabrics

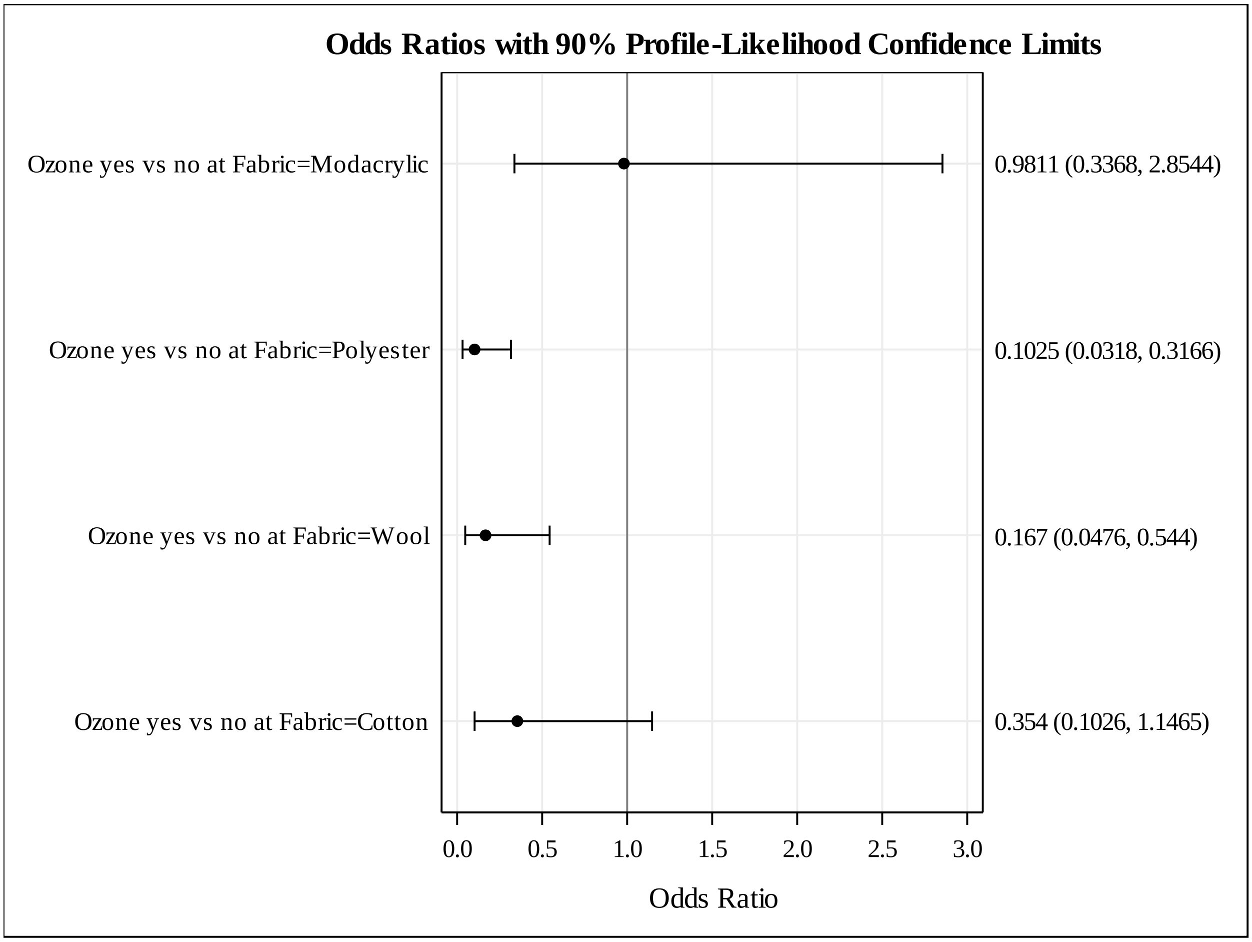
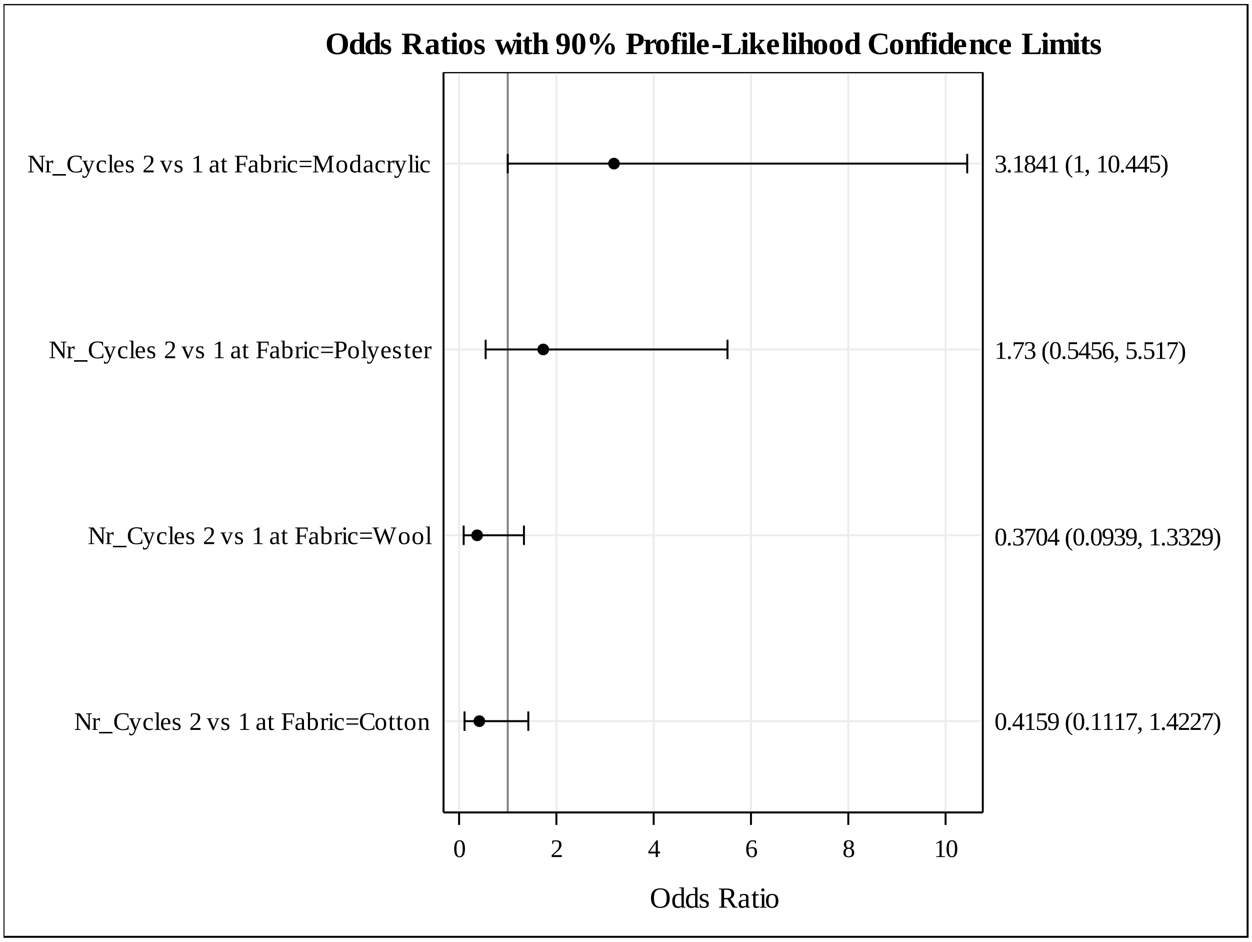


Figure 12. Logistic Odds Ratios for Cycles with Fabrics



7.0 FINDINGS

For the four fabrics in this study, the percents by weight of water needed for saturation are approximately 150% for Merino wool and modacrylic and approximately 250% for cotton and polyester.

The detergent 7th Generation Free & Clear has been identified as effective and at the same time potentially minimally burdensome on water quality. Because this detergent is likely formulated for cleaning cotton, it is advisable in future studies to assess another detergent specifically formulated to clean synthetic fabrics, such as Win.

Published reports indicate that ozone gas in air can sanitize environmental surfaces to various levels of effectiveness at various levels of ozone concentration depending on humidity and duration of exposure. Ultraviolet generation of gaseous ozone in air can readily generate effective concentrations of at least 20 parts per million in a closed chamber and achieve sanitation within 30 minutes.

A solution with a higher detergent concentration produces a statistically significantly greater odor acceptance than does a lower concentration. On the one hand, it may be assumed that 7th Generation detergent is formulated primarily for cleaning cotton. On the other hand, it is known that cleaning synthetics such as modacrylic and polyester is more difficult than cleaning a natural fiber such as cotton.

In further studies, it may be advisable to include a detergent such as Win which is specifically formulated for cleaning synthetic fabrics.

The use of ozone seems statistically significantly to increase the perception of odor in the sense that not applying ozone is preferable. It was not anticipated in this study that fabrics would retain ozone any appreciable time after exposure. Ozone has a sharp and easily perceived odor, even in concentrations which are quite low. A garment rinsing step or other ozone elimination step was not included in this study. Such a finishing step in the process should remove any residual ozone from fabrics. It may very well be useful to include ozone in the cleaning process in order to kill micro-organisms and degrade large molecules for easier suspension in the detergent solution and subsequent removal. Further studies should include one or more rinsing steps and perhaps an ozone neutralization step as well.

The number of cleaning cycles seems neither to increase nor decrease the perception of odor. Modacrylic, and to some extent polyester as well, achieve greater odor acceptance with two cycles, which may be related to the greater difficulty in cleaning synthetic fabrics. The indication that one cycle is preferable to two cycles for cotton and Merino wool may be related to ozone retention by these fabrics.

Applying detergent solution as a mist sufficient to achieve saturation can be effective in eliminating odors from athletically soiled shirts either with or without exposure to ozone. Several cycles of application of detergent solution as a mist and of ozone and mechanical removal of soiled solution will be necessary for thorough cleaning. This is especially true for synthetic fabrics. One or more applications and removal of water mist will be necessary to remove residual ozone. Such rinse cycles will also likely be necessary to remove residual detergent.

8.0 RECOMMENDATIONS

Follow-on studies are recommended to confirm and advance the findings of the screening study presented here. The follow-on studies should use the more effective ZONOsanitech ozonating chamber located in the Advanced Materials Laboratory in the Crew and Thermal Systems Division. This chamber also provides control and recording of ozone concentrations and relative humidity, as well as providing the high humidity needed for effective sanitizing and providing fast catalytic ozone destruction.

The fast catalytic ozone destruction capability of the ZONOsanitech ozonating chamber will likely aid in the reduction or elimination of any ozone retained in garment fabric. Additionally, one or more applications and removal of water mist can be included in the process to remove residual ozone.

In further studies, we would suggest determining the absolute minimum of detergent required for odor removal by titrating down from 13% and determining when the odor becomes perceptible. This reduction in detergent will help to minimize water pollution, the reduction of which is important for the compatibility of a clothing cleaning system with the spacecraft water recovery system.

It is also important to check for detergent foaming during the titration process, as foaming is burdensome for water recovery. It is important to note that the experiment reported here was done with tap water, as water softeners and chelating agents in detergents would not be necessary in a spacecraft, which uses deionized water.

Several cycles of application of detergent solution as a mist and of ozone and mechanical removal of soiled solution will be necessary for thorough cleaning. This is especially true for synthetic fabrics. One or more applications and removal of water mist will likely be necessary to remove residual detergent.

For the harder-to-clean synthetic fabrics, a detergent formulated for synthetic fabrics, such as Win, should be included as well as additional cleaning cycles and one or more rinse cycles.

Another aspect to investigate further is wear time. Further studies should determine the optimal duration of wear before washing, as an over soiled shirt can retain odors beyond the point of removal. The total lifetime of a shirt after repeated wear and washing should also be determined in order to estimate the number of shirts per person required for a Mars mission. A rinse cycle may need to be included in the washing protocol in order to prevent any dermal irritation from detergent otherwise retained in the clothing.

It is also important to note that residual odor from deodorant was left on some shirts after washing. For future studies, we suggest trying additional cleaning and rinsing cycles in order to remove such residual odor. Failing that, we suggest that deodorant should either not be used at all or that only a fragrance-free deodorant be used, as is done currently on the International Space Station.

9.0 REFERENCES

[1] Advanced Exploration Systems (AES) Logistics Reduction Project: Advanced Clothing System for Going to Mars, CTSD-ADV-1267, February 10, 2016.

[2] Soaps and Detergents. The Soap and Detergent Association, New York, 1994.

[3] Horvath, M., L. Bilitzky and J. Hüttner. *Ozone*, 350pp, Monograph 20: Topics in Inorganic and General Chemistry, Elsevier Science Publishers, Amsterdam, 1985, ISBN 0-444-99625-7.

[4] Ozone production from UV, Oxidation Technologies, LLC, http://www.oxidationtech.com/ozone/ozone-production/uv-lamp.html.

[5] Smith, Wayne, Principles of ozone generation, Watertec Engineering Pty Ltd, http://watertecengineering.com/TZ000002%20Principles%20of%20Ozone%20Generation.pdf.

[6] Janie D. McClurkin, Dirk E. Maier, Klein E. Ileleji, Half-life time of ozone as a function of air movement and conditions in a sealed container, *Journal of Stored Products Research*, volume 55, 2013, pages 41-47, ISSN 0022-474X, http://dx.doi.org/10.1016/j.jspr.2013.07.006.

[7] Batakliev, T., Georgiev, V., Anachkov, M., Rakovsky, S., & Zaikov, G. E. (2014), Ozone decomposition, *Interdisciplinary Toxicology*, *7*(2), 47–59, http://doi.org/10.2478/intox-2014-0008.

[8] Ana R. Ribeiro, Olga C. Nunes, Manuel F.R. Pereira, Adrián M.T. Silva, An overview on the advanced oxidation processes applied for the treatment of water pollutants defined in the recently launched Directive 2013/39/EU, *Environment International*, volume 75, 2015, pages 33-51, ISSN 0160-4120, http://dx.doi.org/10.1016/j.envint.2014.10.027.

[9] Ozone use for surface sanitation, Ozone Solutions, http://www.ozonesolutions.com/info/ozone-use-for-surface-sanitation.

[10] Lam, Kenneth K. K., Ozone disinfection of SARS-contaminated areas, Enviro Labs Limited, https://www.ozonetech.com/sites/default/files2/pdf/Ozone_disinfection_of_SARS_Contaminated_Areas.pdf.

[11] Blevins, Suzanne, S., Rizwan Hashmii, Aerobiology Laboratory Associates, Incorporated, http://www.zonoservices.com/wp-content/uploads/2016/05/zono_aerobio_report_for_publication_signed.pdf.

[12] Cannon, Jennifer L., Inactivation of Feline Calicivirus and Murine Norovirus After Exposure to Atmospheric Ozone (20 ppm) with Humidity Control (80%) using the ZONOsanitech Portable Ozone Generator, Center for Food Safety, University of Georgia, February 11, 2011, http://www.zonoservices.com/wp-content/uploads/2016/05/zonosanitech_final_uga.pdf.

[13] http://www.ozonedestructs.com/ozonedestructfaq.htm.

[14] SAS/STAT® 14.1, SAS software version 9.4 (TS1M3) of the SAS System for Microsoft Windows 7 (X64_7PRO). Copyright © 2002-2012 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA, http://support.sas.com/documentation/onlinedoc/stat/index.html.

10.0 APPENDIX

Table 15. Preference Data for Cycle 1

Fabric	Pct_Detergent	Ozone	Nr_Cycles	Participant	Shirt_Code	Cycle_1_Eval_Tester_1	Cycle_1_Object_Tester_1	Cycle_1_Eval_Tester_2	Cycle_1_Object_Tester_2	Cycle_1_Eval_Tester_3	Cycle_1_Object_Tester_3
Wool	7.40	no	1	C	GE05	1	no	1	no	2	no
Wool	7.40	no	2	A	IT1	1	no	2	no	1	no
Wool	13.00	no	1	D	IT23	1	no	1	no	2	no
Wool	13.00	no	2	F	IT13	1	no	1	no	2	no
Wool	7.40	yes	1	C	IT23	1	no	1	no	3	yes
Wool	7.40	yes	2	A	KNICK	1	no	2	no	3	yes
Wool	13.00	yes	1	E	IT13	1	no	1	no	2	no
Wool	13.00	yes	2	B	GE05	1	no	2	no	2	no
Cotton	7.40	no	1	A	UT73	1	no	1	no	3	yes
Cotton	7.40	no	2	B	UT40						
Cotton	13.00	no	1	E	AJT20	1	no	1	no	1	no
Cotton	13.00	no	2	A	UT44	2	no	1	no	2	no
Cotton	7.40	yes	1	C	UT46	1	no	1	no	2	no
Cotton	7.40	yes	2	C	UT45	1	no	2	no	3	yes
Cotton	13.00	yes	1	C	UT44	1	no	2	no	2	no
Cotton	13.00	yes	2	C	BR1	1	no	2	no	2	no
Modacrylic	7.40	no	1	C	PT53	3	yes	3	yes	2	no
Modacrylic	7.40	no	2	D	PT54	1	no	2	no	2	no
Modacrylic	13.00	no	1	E	PT24	3	yes	2	no	2	no
Modacrylic	13.00	no	2	A	PT50	2	no	1	no	2	no
Modacrylic	7.40	yes	1	A	PT49	3	yes	3	yes	2	no
Modacrylic	7.40	yes	2	E	PT24	2	no	3	yes	3	yes
Modacrylic	13.00	yes	1	B	PT35	1	no	2	no	1	no
Modacrylic	13.00	yes	2	E	PT11	1	no	2	no	2	no
Polyester	7.40	no	1	C	NT31	2	no	3	yes	1	no
Polyester	7.40	no	2	A	PNTG	1	no	1	no	2	no
Polyester	13.00	no	1	D	NT50	1	no	2	no	1	no
Polyester	13.00	no	2	E	NT29	1	no	2	yes	2	no
Polyester	7.40	yes	1	C	UT28	2	no	3	yes	2	no
Polyester	7.40	yes	2	E	NT37	2	no	3	yes	2	no
Polyester	13.00	yes	1	E	NT29	2	no	3	yes	2	no
Polyester	13.00	yes	2	A	PNTO	2	no	3	yes	2	no

Table 16. Preference Data for Cycle 2

Fabric	Pct_Detergent	Ozone	Nr_Cycles	Participant	Shirt_Code	Cycle_2_Eval_Tester_1	Cycle_2_Object_Tester_1	Cycle_2_Eval_Tester_2	Cycle_2_Object_Tester_2	Cycle_2_Eval_Tester_3	Cycle_2_Object_Tester_3
Wool	7.40	no	1	C	GE05						
Wool	7.40	no	2	A	IT1	1	no	2	no	2	no
Wool	13.00	no	1	D	IT23						
Wool	13.00	no	2	F	IT13	1	no	1	no	1	no
Wool	7.40	yes	1	C	IT23						
Wool	7.40	yes	2	A	KNICK	2	no	3	yes	3	yes
Wool	13.00	yes	1	E	IT13						
Wool	13.00	yes	2	B	GE05	1	no	2	no	2	no
Cotton	7.40	no	1	A	UT73						
Cotton	7.40	no	2	B	UT40	1	no	1	no	2	no
Cotton	13.00	no	1	E	AJT20						
Cotton	13.00	no	2	A	UT44	1	no	1	no	2	no
Cotton	7.40	yes	1	C	UT46						
Cotton	7.40	yes	2	C	UT45	1	no	2	no	2	no
Cotton	13.00	yes	1	C	UT44						
Cotton	13.00	yes	2	C	BR1	1	no	2	no	2	no
Modacrylic	7.40	no	1	C	PT53						
Modacrylic	7.40	no	2	D	PT54	1	no	2	no	2	no
Modacrylic	13.00	no	1	E	PT24						
Modacrylic	13.00	no	2	A	PT50	2	no	2	no	2	no
Modacrylic	7.40	yes	1	A	PT49						
Modacrylic	7.40	yes	2	E	PT24	1	no	2	yes	2	no
Modacrylic	13.00	yes	1	B	PT35						
Modacrylic	13.00	yes	2	E	PT11	2	no	2	no	2	no
Polyester	7.40	no	1	C	NT31						
Polyester	7.40	no	2	A	PNTG	1	no	2	no	1	no
Polyester	13.00	no	1	D	NT50						
Polyester	13.00	no	2	E	NT29	1	no	1	no	2	no
Polyester	7.40	yes	1	C	UT28						
Polyester	7.40	yes	2	E	NT37	2	no	3	yes	2	no
Polyester	13.00	yes	1	E	NT29						
Polyester	13.00	yes	2	A	PNTO	1	no	1	no	3	yes

Table 17. Ozone Exposure Data

Fabric	Pct_Detergent	Ozone	Nr_Cycles	Participant	Shirt_Code	Ozone_ppm_at_45_min_Cycle_1	Ozone_ppm_at_45_min_Cycle_2
Wool	7.40	no	1	C	GE05		
Wool	7.40	no	2	A	IT1		
Wool	13.00	no	1	D	IT23		
Wool	13.00	no	2	F	IT13		
Wool	7.40	yes	1	C	IT23	6.52	
Wool	7.40	yes	2	A	KNICK	4.2	9.66
Wool	13.00	yes	1	E	IT13	9.66	
Wool	13.00	yes	2	B	GE05	8.05	6.52
Cotton	7.40	no	1	A	UT73		
Cotton	7.40	no	2	B	UT40		
Cotton	13.00	no	1	E	AJT20		
Cotton	13.00	no	2	A	UT44		
Cotton	7.40	yes	1	C	UT46	5.01	
Cotton	7.40	yes	2	C	UT45	10	18
Cotton	13.00	yes	1	C	UT44	5.01	
Cotton	13.00	yes	2	C	BR1	5.84	9.97
Modacrylic	7.40	no	1	C	PT53		
Modacrylic	7.40	no	2	D	PT54		
Modacrylic	13.00	no	1	E	PT24		
Modacrylic	13.00	no	2	A	PT50		
Modacrylic	7.40	yes	1	A	PT49	11.75	
Modacrylic	7.40	yes	2	E	PT24	8	8.05
Modacrylic	13.00	yes	1	B	PT35	11.75	
Modacrylic	13.00	yes	2	E	PT11	4.2	9.66
Polyester	7.40	no	1	C	NT31		
Polyester	7.40	no	2	A	PNTG		
Polyester	13.00	no	1	D	NT50		
Polyester	13.00	no	2	E	NT29		
Polyester	7.40	yes	1	C	UT28	8	
Polyester	7.40	yes	2	E	NT37	10	18
Polyester	13.00	yes	1	E	NT29	9.66	
Polyester	13.00	yes	2	A	PNTO	5.84	9.97