Applied Research & Innovation

Lambton College

Sani Sport testing and optimization for Fire Fighter Equipment Sanitation

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Sani Sport

The science of common sense

Summary

This project focused on assessing the novel ozone-generating cabinet produced by Sani Sport for use in routine disinfection of Firefighters Turnout Gear.

In their work, Firefighters are repeatedly exposed to pathogenic microorganisms. This makes routine cleaning and disinfection of Turnout Gear of paramount importance. The existing cleaning procedure involves time-consuming and cumbersome machine washing and drying. Novel technologies using ozone (O3) as a cleaning, disinfecting and deodorizing agent are receiving growing attention and proven to be effective in sports industry.

The objective of this collaborative project was to modify the current Sani Sport system for the fire fighter gears and perform comprehensive experimentation and analysis to evaluate the newly designed system for various conditions. As first step, the existing Sani Sport unit was redesigned and the ozone generation system was modified so that it could treat the Firefighters Turnout Gear as well as Hazardous Materials entry suits. It was successfully demonstrated that ozone disinfection and deodorization can be applied effectively to “soft” fabrics constituting the Firefighters Turnout Gear using selected human-specific genera of microorganisms. It was also proved that repeated ozone exposure of Firefighters Turnout Gear on Gear does not affect integrity and fabric stability.

The generated results open a possibility to access a new vast market for Sani Sport. The next step for Sani Sport is to start the commercialization activities including production analysis, regulatory approval and marketing.

Contents

Introduction

1.1 Existing approaches for Turnout Gear sanitization

Control of pathogenic and opportunistic microorganisms represents an ongoing challenge for professionals exposed to general public with special needs.

Most of firefighter service calls are for emergency medical assistance that they provide in cases when they arrive before paramedics. This practice exposes firefighters to pathogenic and opportunistic microorganisms such as bacteria, viruses and fungi.

National Fire Protection Association 1851 regulation sets Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting states that "…it is imperative that the protective elements [Turnout Gear] be routinely inspected to ensure that they are clean, well maintained, and still safe" (1). The existing cleaning procedure for Turnout Gear sanitization involves routine machine washing with subsequent drying. This operation is performed by personnel of Fire Departments and Schools of Fire Sciences & Public Safety and is found to be cumbersome and time consuming.

Presently, the need for improved procedures and technologies that will allow straightforward, fast and efficient cleaning of Firefighters Turnout Gear becomes evident.

1.2 Ozone as a disinfecting agent

Novel technologies that use ozone (O_3) as a cleaning, disinfecting and deodorizing agent are currently receiving growing attention and popularity. Ozone is a natural gas with strong oxidizing properties that has capacity to effectively kill broad spectrum of microorganisms. Ozone was shown to be effective in either liquid or gaseous forms on its own or in mixture with other substances such as oxygen and hydrogen peroxide (2).

Some of the possible application of ozone includes sanitization and storage of agricultural products such as fruits and vegetables (3); control of water-borne infections in irrigation (4); treatment of infected wounds in health clinics (5); disinfection of the hospital environment (6).

Ozone treatment as a relatively novel approach to sanitization, has its challenges and limitations among which is its toxicity for human lungs (7) and instability which leads to its conversion into oxygen. While the first of these challenges can be addressed by designing sealed cabinets, the second challenge dictates assessment of each novel application of ozone-based disinfection. So far, no specific recommendations regarding efficient ozone concentration, exposure time, fabric/surface treatment has been established. Research into effectiveness of ozone in each novel application is required.

1.3 Ozone Treatment with Sani Sport Sanitizing Cabinet

Sani Sport Sanitizing equipment presents a cabinet which can generate and circulate ozone in a sealed environment. The cabinet has capacity to de-activate ozone at the end of sanitization cycle before door-opening becomes possible, thus allowing safe working environment.

Current Sani Sport cabinets (Fig. 1) are successfully used in sports industry to sanitize hard plastic sportswear such a hockey shoulder protectors, helmets and gloves. Microbiological analysis performed by BioMedCo demonstrated cabinet capacity to significantly (up to 99%) reduce contamination with influenza Virus A, H1N1, *Staphylococcus aureus*, *Candida albicans*, *Clostridium difficile* and *Aspergillus niger* (8).

Using ozone to disinfect Firefighters Turnout Gear is an attractive alternative to current washing machine-based sanitization described above. However existing design of the Sani Sport equipment does not easily accommodate Firefighters Turnout Gear as the Gear cannot be placed on a "shelf" in the existing Sani Sport cabinets. In addition, no data exist suggesting disinfecting efficiency of ozone treatment of Firefighters Turnout Gear and showing that ozone treatment will not significantly damage the integrity of the Gear thus shortening gear's "working-life".

To address these challenges as well as to meet existing need for efficient Gear sanitization, Sani Sport collaborated with Lambton College School of Fire Sciences and Public Safety, to design a novel cabinet accommodate Firefighters Turnout Gear (Fig. 2). Current project was developed to establish novel cabinet's efficiency and applicability to the needs of Firefighters.

Fig. 1. Example of a current model of Sani Sport sanitizing cabinet for sportswear (from http://www.sani-sport.com/).

1.4 Project realization

a) Overall project goals

1. Provide evidence that ozone disinfection and deodorization can be applied effectively to "soft" fabrics.
2. Modify the design of existing Sani Sport cabinets so that they can be applied to the treatment of Fire-fighters Turnout Gear as well as Hazardous Materials (HazMat) entry suits.
3. Assess the efficiency of ozone treatment in Sani Sport cabinets on human-specific microorganisms.
4. Investigate the effect of repeated ozone exposure of Fire-fighting Turnout Gear on Gear integrity and fabric stability.
5. Assist Sani Sport in advancing into novel market niche that involves Fire Fighting Departments and Schools

b) Project history (Jan 2014 – Dec 2014)

Provided below is a summary of steps that were taken in realization of the project since its beginning in January 2014 until December 2014.

Step 1: Design and build prototype ozone cabinet large enough to contain Fire Fighters Turnout Gear. Following suggestions of Lambton College researchers, a prototype of the cabinet (Fig. 2, a) was constructed by Sani Sport to contain a rack (Fig. 2, b) that fits five sets of Firefighters Turnout Gear (each Gear set comprising jacket, pants, helmet, gloves, boots, Fig 2, c and d)

Step 2: Initial Equipment Assessment. After a number of experimentations, it was found out that prototype Sani Sport cabinet was not suitable for Firefighters Gear cleaning as its production of ozone (max 19 ppm) was too low to achieve microbial killing on test plates. It was suggested to the company to introduce modifications increasing ozone production capacity of the cabinet (report #1).

Step 3: Equipment Redesign and Modification. Cabinet ozone generation was maximized to highest ozone volume possible under current design, achieving longer residence time (performed by Sani Sport).

Step 4: Equipment assessment following modification. Comprehensive set of experiments was performed to study the modified equipment performance for different contamination scenarios. Maximum ozone production by cabinet was increased to 43-59 ppm, however no significant reduction of Gear contamination was achieved over two-hour operation cycle. In addition inconsistency in ozone generation and cycle time was observed. It was suggested to the company to increase ozone production levels and consistency as well as to reduce overall operation time (report #2).

Step 5: Secondary Equipment Redesign and Modification. According to the assessment results, SaniSport Ozone generation method was modified / enhanced further to be able to have even higher ozone volume, longer residence time and more controllability.

c) Current project goals (Dec 2014 – May 2015)

Listed below are the goals for the final period of the project from December 2014 until project end in May 2015, results for which are presented in the current report.

1. To perform a comprehensive set of experiments to study the effect of secondary equipment redesign and modification on its performance for different operating (cabinet load, single jacket vs full rack load containing 5 Gear sets) and contamination scenarios (bacterial and fungal contaminants, soil levels).
2. To assess effect of repeated ozone exposure on integrity of Gear fabric (fabric tests).

Fig. 2. Sani Sport cabinet for sanitization of Firefighters Turnout Gear. a) Prototype of a cabinet in Lambton College School of Fire Sciences and Public Safety. b) Empty Gear drying rack. c) "Full load", rack loaded with five Gear sets each comprising jacket, pants, helmet, boots, and gloves. d) "Single load", rack loaded with one jacket (arrow points to fan activated when the rack is plugged into the mains). e) Plug-in for the rack inside of the cabinet. f) Electrical assembly for the plug inside of the cabinet.

Experimental Approach

2.1 Materials

a. Microorganisms and media

E.coli strain HB101 was obtained from BIO-RAD, cat # 1660408. *Fleischmann's yeast, S. cerevisiae* were purchased from local grocery store. Microorganisms were grown in liquid (LB, Miller) or solid (LB Agar, Miller) media from Fisher Scientific. 1% of sucrose was added to the media for S. cerevisiae. Prior to use, media was sterilized in autoclave at 121°C for 15 min.

b. Firefighters Gear

All garments used in the Sani Sport testing and optimization project meet the Garment Requirements of National Fire Prevention Association (NFPA) 1971, 2013 Edition for Fire Fighter Protective Clothing. Firefighters Gear was purchased from following suppliers: Acklands Grainger Inc (1327 Plank Road, Sarnia, ON, N7T 7H3), Canadian Safety Equipment Inc (2465 Cawthra Road, Unit 114, Mississauga, ON, L5A 3P2) and Safedesign Apparel Ltd (34 Torlake Crescent, Toronto, ON, M8Z 1B3).

2.2 Procedures for microbiological testing

a) Experimental set up

Schematic representation of experimental set up is shown on Fig. 3. Microorganisms were grown in liquid media for two days either at 37°C (*E.coli*) or at room temperature (*S.cerevisiae*). Equal amount of microbial cultures were applied on at least three different locations on two sets of Gear, "Test Gear" and "Control Gear". "Test Gear" and "Control Gear" were placed on a Gear-drying racks (Fig. 2, b and Fig. 3). "Test Gear" rack was rolled inside the Sani Sport equipment for sanitizing cycle. "Control Gear" rack was left outside for the duration of sanitization cycle. At the end of the cycle, the designated locations of the Gear where cultures were initially applied were swabbed with sterile foam swabs. Fresh swab was used per location and smeared on solid media in Petri dishes, one location per swab per Petri dish (hereafter "experiment #"). All plates were incubated at 37°C for 18 h. Following that, the plates were removed and remaining bacterial growth was assessed by counting colony forming units (cfu). Efficiency of microorganisms killing by ozone (Average Microbial Kill Rate, %) was estimated by comparing number of surviving colonies (cfu) from the swabs obtained from the "Test Gear" and "Control Gear" according to the following formula:

$$\text{Average Microbial Kill Rate, \%} = \frac{\text{CFU "Control Gear"} - \text{CFU "Test Gear"}}{\text{CFU "Control Gear"}} \text{ X100}$$

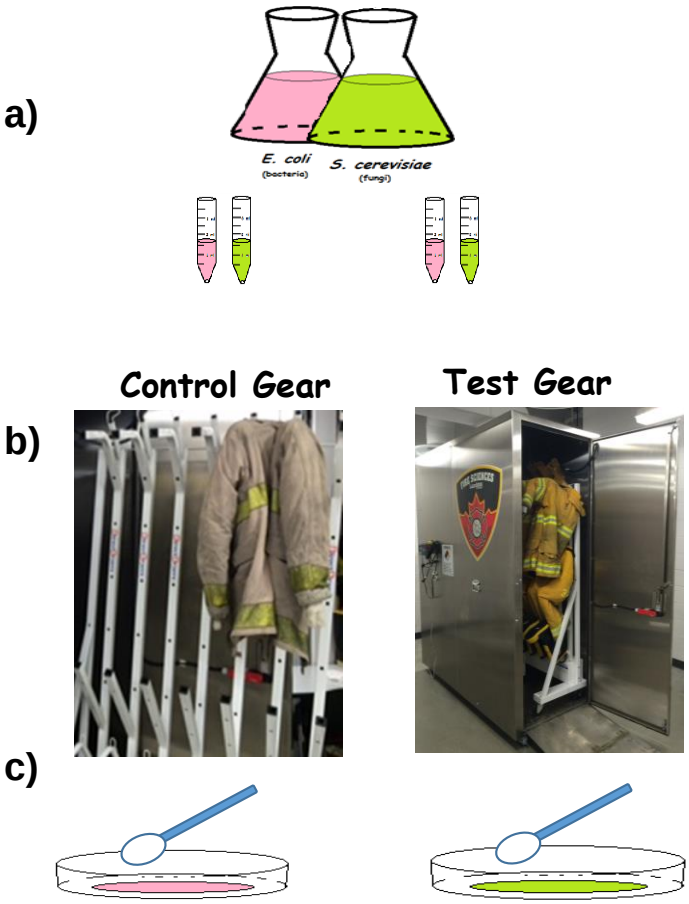


Fig. 3. Schematic representation of microbiological testing of Sani Sport cabinet. a) equal amounts of freshly prepared microbial cultures of bacteria (*E. coli*) and fungus (*S. cerevisiae*) are applied to the designated places on the Gear; b) "Test Gear" is placed on the rack inside Sani Sport cabinet and exposed to ozone; "Control Gear" is left on the rack outside of the cabinet; c) after completion of cabinet cycle, experimental spots on test and control Gear were swabbed onto fresh culture dishes and incubated at 37°C for 18 hours.

b) Effect of Gear contamination by different types of microorganisms

The effect of ozone generated by Sani Sport cabinet was assessed on bacterial (*E.coli*) and fungal (*S. cerevisiae*) cultures. For each Sani Sport cycle, cultures were applied at three separate locations on a Gear set. Experiment was repeated at least three times.

c) Effect of different degree of gear contamination (soil level)

Microbial cultures were applied to the gear in two different concentrations: $6x10^9$ cfu/ml (non diluted, *E.coli*), $6x10^7$ cfu/ml (non-diluted, *S. cerevisiae*) and $1.2x10^9$ cfu/ml (diluted, *E. coli*), $1.2x10^7$ cfu/ml (diluted, *S.cerevisiae*). Diluted cultures were prepared from non-diluted cultures using freshly sterilized medium. For each Sani Sport cycle, diluted and not-diluted cultures were freshly applied at 0.5 ml/spot in three different location on a Gear jacket. The test was repeated at least three times.

d) Effect of Sani Sport cabinet load

To assess cabinet efficiency for low load, Sani Sport cycle was run with single jacket per rack (single jacket, Fig. 2, d). For high load cycle, "Test Gear" jacket with smeared cultures was placed on a rack containing four other Gear sets (full load, Fig. 2, c). One Gear set comprised jacket, pants, helmet, gloves and boots.

e) Effect of modification (additional air blowing)

Sani Sport cabinet was modified to introduce electrical plug-in on the inside wall (Fig. 2, e, f) to enable activation of the fan on a drying rack holding Gear (arrow on Fig. 2, d). Before beginning of the sanitization cycle, the rack was plugged in to initiate additional air/ozone blowing through the Gear on the rack. All experiments were conducted with diluted and non-diluted cultures of *E.coli* at full load of Sani Sport cabinet as described above.

2.3 Procedures for fabric testing

A set of Firefighters Gear comprising one helmet, five bunker coats and two bunker pants were repeatedly exposed to at least ten cycles of ozone t in Sani Sport cabinet (active Gear). Four new bunker coats and five new bunker pants were used as controls (inactive Gear) and were not subjected to Sani Sport cabinet treatment. To assess Gear fabric integrity, active and inactive Gear sets were sent to NFPA 1851 certified laboratory, Inservus Management Systems (1971 Bond St, North Bay, ON P1B 4V7; http://www.inservus.net/). The following parameters were analyzed: Moisture Leak, Shell Strength, Trim Reflectiveness, Thread Strength, Moisture/Thermal Evaluation Detailed protocol of the tests can be found in Appendix 1 and 2.

3. Results and Discussions

3.1 Microbiological testing

a) Summary of results

Sani Sport cabinet successfully eliminated microbial contaminations achieving average efficiency of 92% (for bacteria, *E.coli*) and 95% (for fungi, *S. cerevisiae*) (Fig. 4). Summary of the experimental conditions and results is shown in Table 1; details of individual experiments expanded in Tables 2 (bacteria, *E.coli*) and 3 (fungi, *S. cerevisiae*); details of each experiment with pictures are presented in Appendix 3.

Presented results were obtained in 60 experiments designed to assess effectiveness of Sani Sport in Firefighters Gear sanitization in the following set ups:

i. Gear contamination by different types of microorganisms (bacteria or fungi).
ii. Different degree of Gear contamination (soil level).
iii. Sani Sport cabinet load (almost empty, containing one jacket or fully loaded with five sets of Gear)
iv. Additional air-blowing through the rack

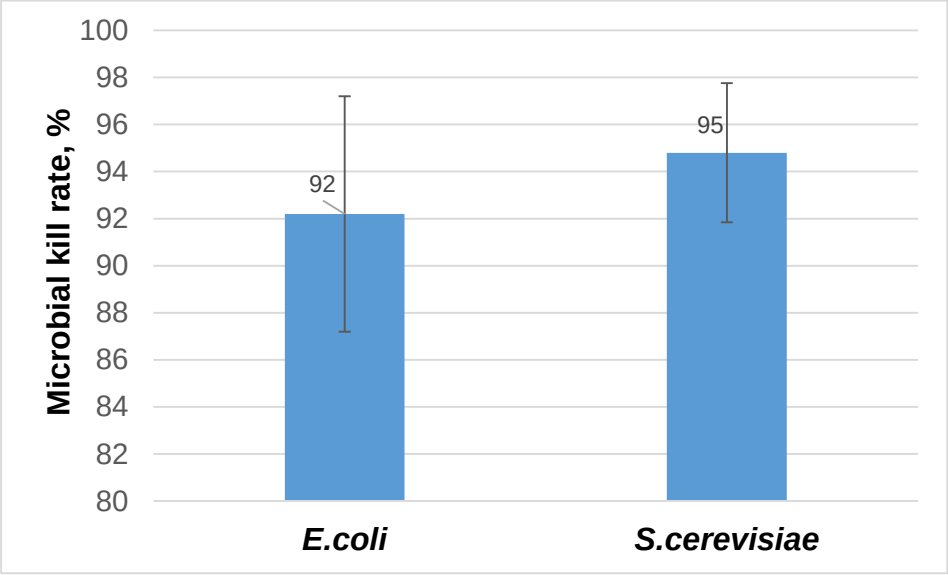


Fig. 4 Sani Sport cabinet efficiency in eliminating microbial contamination. Microbial killing rate is shown as an average for all tests (described in details in Tables 2 and 3). Error bars indicate standard deviation

Table 1. Summary of experiments performed in assessing disinfecting potential of Sani Sport ozone-generating cabinet.

"Culture": experiments were performed to assess cabinet effectiveness in reducing bacterial (*E.coli*) and fungal (*S. cerevisiae*) contamination of the Turnout Gear;

"Dilution": high and low soil levels were tested with cultures applied respectively with (dilution, x5) and without (no dilution, x1) dilution;

"Additional Air blowing": cabinet performance with and without additional air circulation through the rack was assessed for low soil levels with *E.coli*;

"Average O_3 max, ppm": maximal levels of ozone were recorded for each cycle of cabinet; the data show average value of ozone for each set of experimental conditions;

"Cabinet load (single/full, S/F)": for each experiment, Turnout Gear was loaded on a rack that was subsequently positioned in Sani Sport cabinet. Cabinet was loaded either with single jacket per rack (S, "single") or with fully loaded rack containing five full Gear sets (F, "full") (1 Gear set comprising jacket, pants, helmet, boots, gloves).

"Control Gear, average cfu": microbial cultures were applied in similar dilutions and locations on control and test Gear. Control Gear was left outside of the cabinet during duration of sanitization cycle. Microorganisms were swabbed and spread on nutrient agar-containing petri dish. Survival of microorganisms was assessed by counting colony forming units (cfu). The data show average cfu of the indicated number of experiments for each set of experimental conditions.

"Test Gear, average cfu": microbial cultures were applied in similar dilutions and locations on control and test Gear. Test Gear placed inside of the cabinet and subjected to sanitization cycle. After cycle completion, microorganisms were swabbed and spread on nutrient agar-containing petri dish. Survival of microorganisms was assessed by counting colony forming units (cfu). The data show average cfu of the indicated number of experiments for each set of experimental conditions.

"Average kill, %": efficiency of sanitization was determined for each set of experimental conditions by calculating relative number of killed microorganisms.

Experimental Conditions						Experimental Results		
Total # of experiments	Culture	Dilution	Additional Air-blowing	Average O_3 max ppm	Cabinet load (Single jacket/Full rack) S / F	Control Gear, average cfu	Test Gear, average cfu	Microbial kill rate, average %
6	bacteria	no	no	513	S	1973	95	**94.1**
6	bacteria	yes	no	513	S	1683	5	**99.7**
7	bacteria	no	no	99.9	F	3289	253	**86.3**
8	bacteria	yes	no	102.4	F	175	31	**91.2**
10	bacteria	yes	yes	32.2	F	614	44	**90.0**
6	fungi	no	no	513	S	3404	19	**99.0**
5	fungi	yes	no	513	S	1477	62	**94.5**
6	fungi	no	no	97	F	1387	64	**93.8**
6	fungi	yes	no	97	F	715	60	**92.0**

Table 2. Expanded from Table 1. Experimental conditions and results for assessment of bacterial (*E.coli*) kill rate after exposure of Turnout Gear to Sani Sport cabinet.

See Table 1 for details

Experimental Conditions					Experimental Results			
Experiment #	Dilution	Additional Air-blowing	max O_3 ppm	Cabinet load (Single jacket/Full rack) S / F	Control Gear, cfu	Test Gear, cfu	Microbial kill rate, %	Average microbial kill rate,%
1	no	no	490	S	1492	179	88.0	**94.1**
2	no	no	490	S	532	66	87.6	
3	no	no	490	S	1152	16	98.6	
4	no	no	536	S	2208	26	98.8	
5	no	no	536	S	2400	93	96.1	
6	no	no	536	S	4056	190	95.3	
7	yes	no	490	S	1920	1	99.9	**99.7**
8	yes	no	490	S	552	3	99.5	
9	yes	no	490	S	716	3	99.6	
10	yes	no	536	S	3048	18	99.4	
11	yes	no	536	S	1192	3	99.7	
12	yes	no	536	S	2672	2	99.9	
13	no	no	86	F	7952	512	93.6	**86.3**
14	no	no	86	F	3344	296	91.1	
15	no	no	86	F	3664	216	94.1	
16	no	no	107	F	3312	316	90.5	
17	no	no	107	F	2848	118	95.9	
18	no	no	107	F	1792	264	85.3	
19	no	no	120	F	108	50	53.7	
20	yes	no	86	F	75	6	92.0	**91.2**
21	yes	no	86	F	130	0	100.0	
22	yes	no	86	F	48	2	95.8	
23	yes	no	107	F	50	2	96.0	
24	yes	no	107	F	64	4	93.8	
25	yes	no	107	F	41	2	95.1	
26	yes	no	120	F	400	52	87.0	
27	yes	no	120	F	588	179	69.6	
28	yes	yes	15	F	91	17	81.3	**90.0**
29	yes	yes	15	F	82	25	69.5	
30	yes	yes	30	F	1084	116	89.3	
31	yes	yes	30	F	1000	111	88.9	
32	yes	yes	43	F	1256	90	92.8	
33	yes	yes	43	F	1424	19	98.7	
34	yes	yes	30	F	234	24	89.7	
35	yes	yes	30	F	321	14	95.6	
36	yes	yes	43	F	378	12	96.8	
37	yes	yes	43	F	268	7	97.4	

Table 3. Expanded from Table 1 Experimental conditions and results for assessment of fungal (*S. cerevisiae*) kill rate after exposure of Turnout Gear to Sani Sport cabinet.

See Table 1 for details

Experimental Conditions					Experimental Results			
Experiment #	Dilution	Additional Air-blowing	max O_3 ppm	Cabinet load (Single jacket/Full rack) S / F	Control Gear, cfu	Test Gear, cfu	Microbial kill rate, %	Average microbial kill rate,%
1	no	no	490	S	4112	10	99.8	**99.0**
2	no	no	490	S	1744	33	98.1	
3	no	no	490	S	5088	3	99.9	
4	no	no	536	S	1832	7	99.6	
5	no	no	536	S	1584	57	96.4	
6	no	no	536	S	6064	1	100.0	
7	yes	no	490	S	1128	356	68.4	**94.5**
8	yes	no	490	S	564	7	98.8	
9	yes	no	490	S	2432	2	99.9	
10	yes	no	536	S	1920	1	99.9	
11	yes	no	536	S	1168	3	99.7	
12	yes	no	536	S	1648	0	100.0	
13	no	no	86	F	2936	53	98.2	**93.8**
14	no	no	86	F	880	184	79.1	
15	no	no	86	F	1312	8	99.4	
16	no	no	107	F	1568	32	98.0	
17	no	no	107	F	696	14	98.0	
18	no	no	107	F	928	92	90.1	
19	yes	no	86	F	496	6	98.8	**92.0**
20	yes	no	86	F	752	2	99.7	
21	yes	no	86	F	920	51	94.5	
22	yes	no	107	F	880	152	82.7	
23	yes	no	107	F	648	140	78.4	
24	yes	no	107	F	592	11	98.1	

b) The rational, details and results for each of these settings are discussed below.

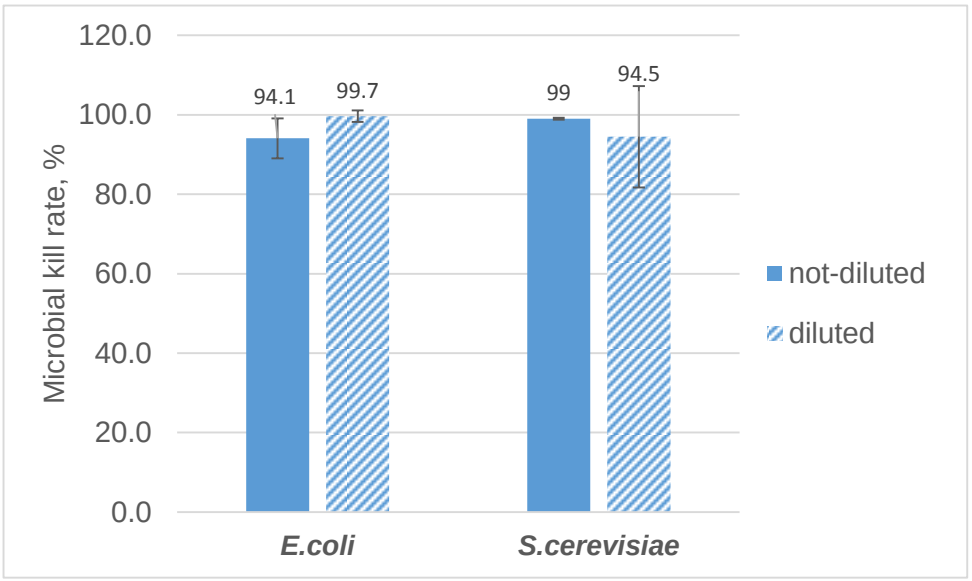
i. Gear contamination by different types of microorganisms

In separate experimental set-ups, two non-pathogenic human-specific types of microorganisms, bacteria (*E.coli*) and fungi (*S. cerevisiae*), were tested for survival after Sani Sport cabinet treatment. For each cabinet cycle, tested microorganisms were applied in at least three different locations on two brand new sets of Firefighters Turnout Gear. One of the sets was designated as a "Test Gear" another as "Control Gear". "Test Gear" was loaded on the rack and placed inside Sani Sport cabinet for sanitization cycle, while "Control Gear" was left outside of Sani Sport cabinet. After completion of sanitization cycle, relative number of residual microorganisms was assessed as described in Materials and Methods. Sani Sport cabinet efficiently eliminated both types of contaminants achieving top efficiency of 99.7% and 99% for bacterial and fungi respectively. Soil level of the Gear (tested with diluted and non-diluted cultures) had no significant effect on cabinet effectiveness although greater effects were observed with both types of microorganisms applied in diluted state. Cabinet load had no significant effect on performance however higher killing rates were achieved for single jacket/rack load (94.1-99.7%) than for full rack load (86.3-93.8%) (Fig. 5, a) and b). The observed difference in cabinet performance can be explained by the maximal concentration of ozone, which was higher during the single jacket/rack load (Table 1, 513 ppm) than during full rack load (Table 1, 97-102.4 ppm).

ii. Different degree of Gear contamination (soil level)

Microbial cultures were applied to the Gear as not diluted or diluted, followed by sanitization cycle in Sani Sport cabinet. Culture dilution rate (five-time) was chosen experimentally: no bacterial recovery was possible with higher dilutions of microbial cultures (results not shown). Our experiments show, that assessed soil level of the Gear had no significant effect on Sani Sport sanitization effectiveness (Tables 2, 3 and Fig. 5). Slightly higher kill rate was observed for *E.coli* when experiments were performed at lower soil level (with diluted cultures) rather than with higher soil level. During single jacket/rack load, lower level of microbial contamination (diluted) resulted in average 99.7% of microbial kill rate compared with 94.1% for higher contamination level (not diluted). Similar trend for *E.coli* was observed during full rack load of cabinet with average 91.2% kill rate for low and 86.3% for high contamination levels.

a)



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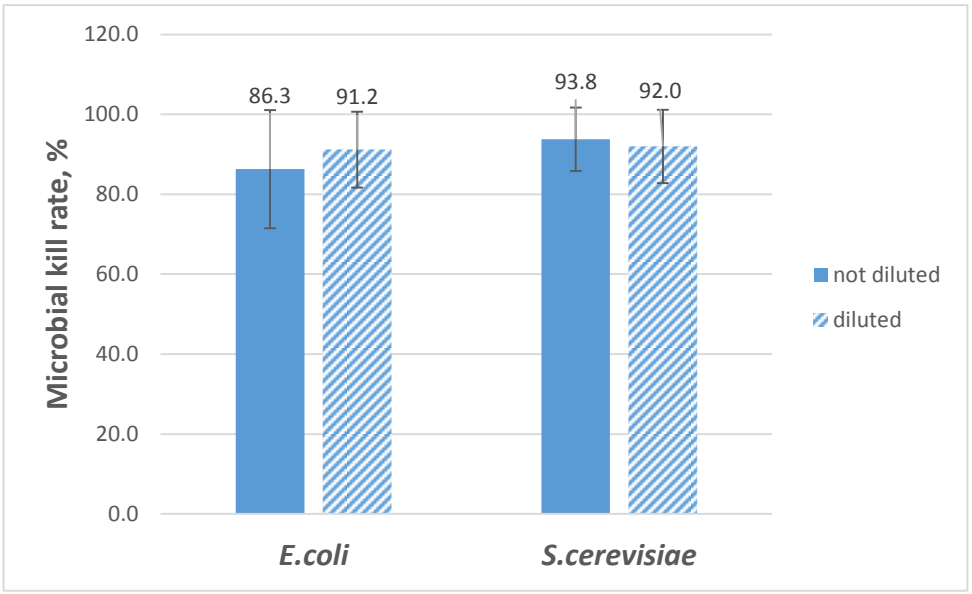
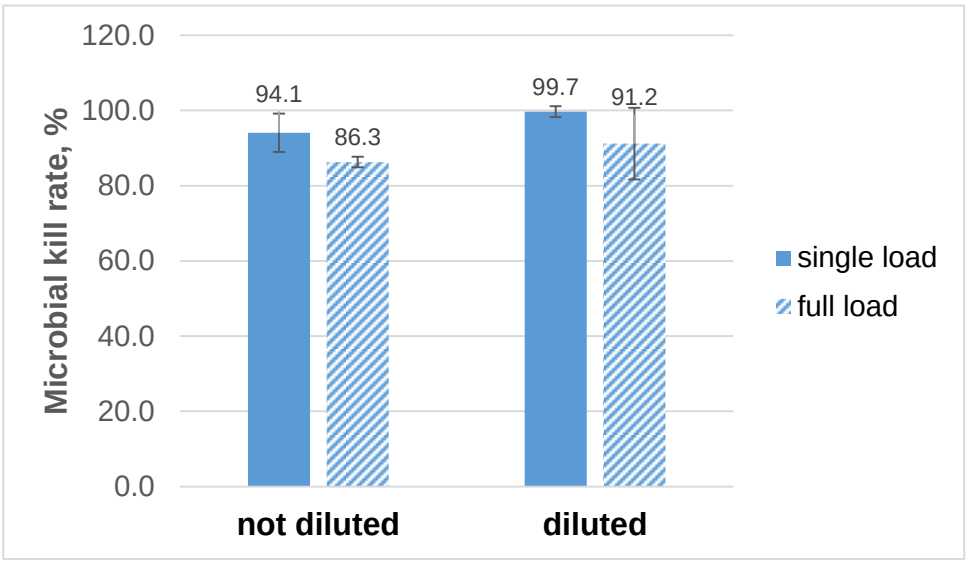


Fig. 5 Cabinet effectiveness in eliminating and different types of microbial contaminants. Average microbial kill rate is shown for bacterial (*E.coli*) and fungal (*S. cerevisiae*) contaminants. Different contamination levels were tested with not diluted and diluted cultures. Assessment was performed for (a) single jacket/rack cabinet load and for (b) full rack load.

iii. Sani Sport cabinet load (one jacket vs fully loaded with five sets of Gear)

Effectiveness of Sani Sport cabinet was assessed for low cabinet load (single load) with single jacket/rack and high cabinet load (full rack load) with 5 sets of Gear/rack, each set containing jacket, pants, boots, helmet and gloves (Fig. 6). No significant difference in Sani Sport disinfection efficiency was observed in operational cycles with single or full rack loads. For *E.coli*, average microbial kill rate was slightly higher for single load cycles achieving 94.1-99.7% as compared with 86.3-91.2 for full rack load. Similar trend was observed for *S.cerevisiae* with single load cycles achieving 99-94.5% as compared with 93.8-92.0 for full rack load. The observed difference in cabinet performance can be explained by the maximal concentration of ozone, which was higher during the single jacket/rack load (Table 1, 513 ppm) than during full rack load (Table 1, 97-102.4 ppm).

a)



b)

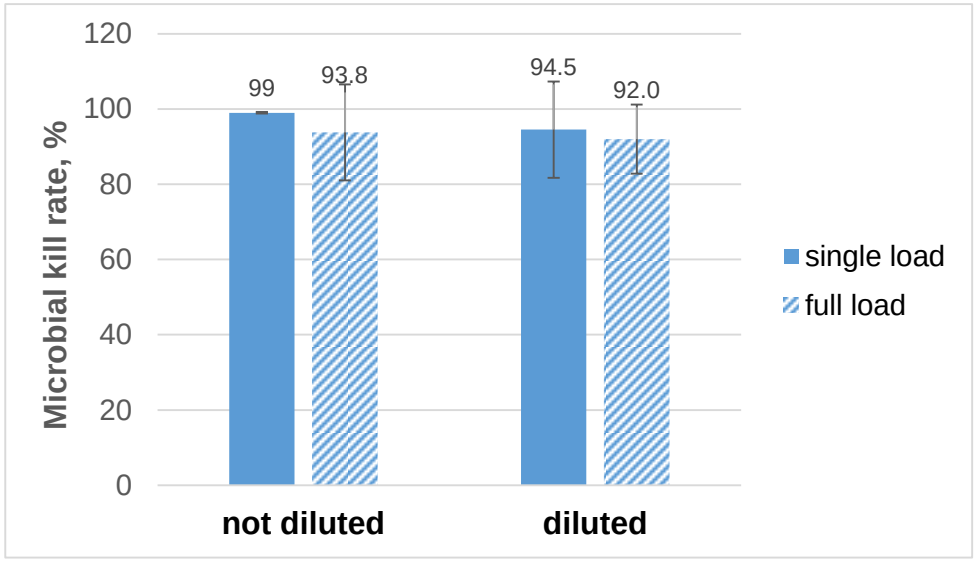


Fig. 6 Cabinet effectiveness and load. Effectiveness of Sani Sport cabinet was assessed for low cabinet load (single load, 1 jacket/rack) and high cabinet load (full load, 5 sets of Gear/rack). Average microbial kill rate is shown for not-diluted and diluted cultures. Assessment was performed for (a) *E. coli* and (b) *S. cerevisiae*.

iv. Additional air-blowing through the rack

One of the specialties Firefighters Gear is that its fabric is air – impermeable. In order to achieve efficient delivery of sanitizing ozone to the Gear insides, cabinet was modified to include an electrical mains. This modification allows plugging of the Gear loading rack once it is inside the cabinet thus providing additional air/ozone blowing through the rack. In a separate set of experiments we tested the effect of the introduced modification on Sani Sport cabinet efficiency in eliminating bacterial (*E.coli*) contamination (Table 1, 2, and Fig. 7). Sani Sport cabinet was efficient in eliminating *E.coli* during full rack load cycle. Comparable microbial kill rates were achieved during cabinet operation with (modified) and without additional air blowing (original design), resulting in respective 91.2% and 90% of average microbial kill rates.

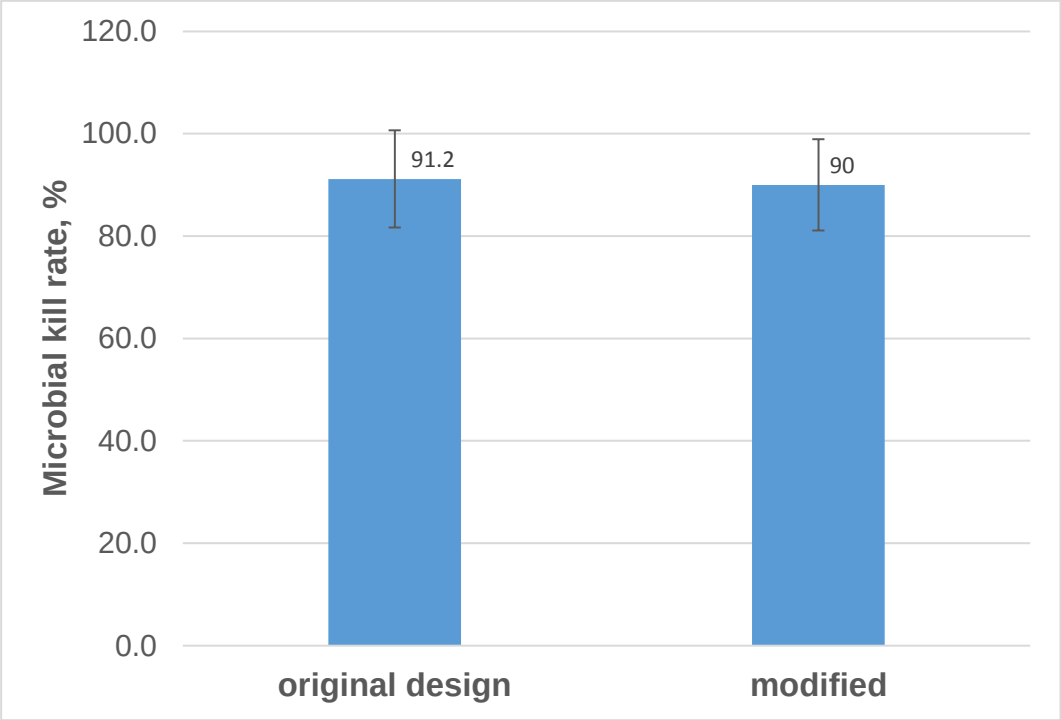


Fig. 7 Effect of cabinet modification (with additional air blowing) on its effectiveness. Sani Sport cabinet was modified to include electrical mains allowing additional air blowing through the rack during cabinet operation. Microbial kill rate achieved by cabinet without additional air blowing (original design) was compared to that of modified cabinet.

3.2 Fabric testing

Firefighters Turnout Gear integrity is a primary concern when testing best sanitization approaches. Repeated application of the ozone could potentially damage Gear fabric and thus render the Gear unusable. Assessment of fabric integrity after ozone exposure was therefore one of the primary goals of this project.

Gear testing was performed as described in Materials and Methods and Appendix 2. After repeated exposure of the Gear set to Sani Sport cabinet cycles (Active Gear), it was compared to the brand new Gear set (Inactive Gear). Active Gear set consisted of one helmet, five new bunker coats and two bunker pants that are were exposed to Sani Sport cabinet sanitization cycles. Inactive Gear set consisted of four new bunker coats and five new bunker pants that were not exposed to Sani Sport cabinet.

The performed testing procedures included: Moisture Leak, Shell Strength, Trim Reflectiveness, Thread Strength, Moisture/Thermal Evaluation.

The results of the tests are shown in Table 4 and summarized in Inservus report letter (see Appendix 1). The results of testing performed by Inservus Management Systems were all positive and indicate that there was no sign of deterioration of the bunker gear components after repeated ozone exposure performed for this project. The conclusion reached after Inservus tests was that “bunker gear is safe to wear and is recommended for active service in the fire industry”.

Table 4. Fabric testing

Fabric parameters were tested for Gear set that was subjected to repeated sanitization cycles in Sani Sport cabinet (Active Gear) and brand new Gear set (Inactive Gear).

GEAR SET	ITEM	SERIAL	MANU	YEAR	SIZE	COMMENT &NAME	Fabric testing results			
							MOISTURE LEAK	SHELL STRENGTH	TRIM REFLECTABILITY	THREAD STRENGTH
ACTIVE GEAR	PS/PL	2014456	FYREPEL	Feb-13	36-30	FS-P4011	PASS	PASS	PASS	PASS
	PS/PL	2013461	FYREPEL	12-Aug	40-30	FS-P4005	PASS	PASS	PASS	PASS
	CS/CL	2013605	FYREPEL	12-Sep	42	FS-C4007	PASS	PASS	PASS	PASS
	CS/CL	2013444	FYREPEL	12-Aug	44	FS-C4042	PASS	PASS	PASS	PASS
	CS/CL	4602584	GLOBE	13-Oct	46	FS-C4042	PASS	PASS	PASS	PASS
	CS/CL	2013626	FYREPEL	13-Sep	46	FS-C4003	PASS	PASS	PASS	PASS
	CS/CL	4602573	GLOBE	13-Oct	42	FS-C4045	PASS	PASS	PASS	PASS
INACTIVE GEAR	PS/PL	4602604	GLOBE	13-Oct	38/30	FS-P4043	PASS	PASS	PASS	PASS
	PS/PL	2014403	FYREPEL	13-Feb	40/30	FS-P4010	PASS	PASS	PASS	PASS
	PS/PL	4602605	GLOBE	13-Oct	38/30	FS-P4036	PASS	PASS	PASS	PASS
	PS/PL	2014390	FYREPEL	12-Aug	40/30	FS-P4006	PASS	PASS	PASS	PASS
	PS/PL	4602594	GLOBE	13-Oct	38/28	FS-P4037	PASS	PASS	PASS	PASS
	CS/CL	2013442	FYREPEL	12-Aug	44	FS-C4008	PASS	PASS	PASS	PASS
	CS/CL	2013449	FYREPEL	12-Aug	46	FS-C4004	PASS	PASS	PASS	PASS
	CS/CL	2014733	FYREPEL	13-Feb	40	FS-C4005	PASS	PASS	PASS	PASS
	CS/CL	4602580	GLOBE	13-Oct	46	FS-C4044	PASS	PASS	PASS	PASS
	HELMET	#11	CAIRNS							

4. Conclusion

The final stage of the project covering period from December 2014- May 2015 was focusing on assessing sanitization efficiency of Sani Sport cabinet that was modified by the manufacturer according to Lambton College research team recommendations.

The project achieved satisfactory results in a microbiological analysis and fabric testing.

4.1 Microbiological analysis

Comprehensive set of experiments was performed to study performance of modified Sani Sport cabinet in different operating and contamination scenarios among which were tested:

- cabinet load, almost empty vs fully loaded (single jacket vs full rack load);
- different types of contaminants, bacterial (*E. coli*) and fungal (*S. cerevisiae*);
- soil level of the Gear, high soil level vs reduced soil level (with not diluted and diluted cultures).

Sani Sport cabinet was effective when operated either in almost empty and fully loaded condition. There was achieved 92% and 95% reduction of bacterial and fungal contamination. No significant difference was observed between high and reduced soil levels of the Gear.

4.2 Fabric testing

Effect of repeated usage of Sani Sport cabinet on integrity of Gear fabric (fabric tests) was also performed by a NFPA-certified laboratory that tested moisture leak, shell strength, trim reflectability, and thread strength. It was demonstrated, that after a number of exposures performed during current assessment, no adverse effects on Gear fabric integrity was observed as reported by Inservus Management Systems Inc.

In conclusion, our experiments indicate that ozone disinfection and deodorization provided by Sani Sport cabinet can be applied effectively to Firefighters Turnout Gear without affecting fabric intensity

5. Recommendations and Further Directions

In our experiments, Sani Sport cabinet has proven to be a successful equipment for Firefighters Turnout Gear sanitization. The company implemented most of the recommendations suggested by the Lambton College research team. Among further improvements to the cabinet could be listed the following:

- Reduction of the cycle length allowing to increase number of Gear sets disinfected per day.
- More flexible control unit allowing more control of the cycle, such as duration of exposure to maximal ozone concentrations.
- Automation or semi-automation of rack rolling in and out of cabinet allowing usage of minimal physical force in operation of the cabinet and ensure prevention of workplace injuries.

The outcomes of this research could be used by Sani Sport to enter new market niche including fire-fighting departments in Canada and abroad as potential customers.

Lambton College will be able to assist Sani Sport in its commercialization efforts by demonstrating cabinet operation in its Scholl of Fire Sciences and Public Safety. Lambton College will also be able to implement further cabinet optimization by developing and designing automated/semi-automated rack positioning system of the cabinet.

Possible future expansion of Sani Sport manufacturing facilities into the Sarnia-Lambton area will contribute to economic growth in the region by creating new manufacturing job opportunities and increasing cash flow in the province.

6. References

(1) National Fire Protection Association 1851 regulation.

(2) Tachikawa M, Yamanaka K. Synergistic disinfection and removal of biofilms by a sequential two-step treatment with ozone followed by hydrogen peroxide. 2014 Water Research, v 64, pg. 94–101.

(3) Perry, J.J., Yousef, A.E. Decontamination of raw foods using ozone-based sanitization techniques. 2011 Annual review of food science and technology, v. 2, pg. 281-298

(4) Raudales, R.E., Parke, J.L., Guy, C.L., Fisher, P.R. Control of waterborne microbes in irrigation: A review. 2014 Agricultural Water Management, v 143, pg. 9-28

(5) Białoszewski D, Kowalewski M: Superficially, longer, intermittent ozone therapy in the treatment of the chronic, infected wounds. 2003 Ortop Traumatol Rehabil, v 5, pg. 652–658.

(6) Davies A, Pottage T, Bennett A, Walker J: Gaseous and air decontamination technologies for Clostridium difficile in the healthcare environment. 2011 J Hosp Infect, v 77, pg. 199–203.

(7) Bocci, V, Borrelli, E. Travagli, V. Zanardi, I. The ozone paradox: Ozone is a strong oxidant as well as a medical drug. 2009 Medicinal Research Reviews, v 29/4, pg 646-682.

(8) http://www.sani-sport.com/pdf/VE_lab_results_2015.pdf

Appendices

Appendix 1

Summary of Fabric Testing Results (Inservus)

1971 Bond Street. North Bay, Ontario P1B 4V7
Tel.: 705 476-4022
1-888-NSERVUS(673-7887)
Fax: 705 476-6474
inservus@bellnet.ca
24 Hour Emergency Response

Kevin Graham
Industrial Operations Coordinator
Lambton College
School of Fire & Public Safety
519-542-7751

April 17, 2015

RE: Bunker Gear (Personal Protective Equipment) Testing

Dear Mr. Graham,

Inservus Management Systems is a verified third party service provider for clean and repair of personal protective equipment and are authorized to do so by Underwriters Laboratories. As per your request, we have recently performed a series of testing procedures on PPE that you have provided to us.

Your inventory of gear consisted of one helmet, five bunker coats and two bunker pants that are currently active (used) and four bunker coats and five bunker pants that are inactive (new) in the fire industry.

The testing procedures performed on your PPE (Moisture Leak, Shell Strength, Trim Reflectiveness, Thread Strength, Moisture/Thermal Evaluation) are outlined in this document along with the PPE testing and results in the excel spreadsheet provided.

The results of testing performed by Inservus Management Systems were all positive and indicate that there is no sign of deterioration of the bunker gear components, as a result, your bunker gear is safe to wear and is recommended for active service in the fire industry.

If you require further information regarding our finding, please feel free to contact us anytime. Thank you for your continued business and have a fire safe day!

Best Regards,
Mike Croghan
Quality Assurance Manager
Inservus Management Systems

Appendix 2

Fabric Testing Protocol (Inservus)

MOISTURE LEAK TESTING

This evaluation method is applied to the moisture and thermal barrier liners found in the structural firefighting protective garment elements. At a minimum, the front and back panels of each protective garment shall be evaluated using three different moisture barrier material areas and three different moisture barrier areas with a seam. The evaluation apparatus consist of a hydrostatic fluid tester that provides for the pressurization of water against garment element moisture barrier at a pressure of 1 PSI for a period of 10 seconds.

SHELL STRENGTH TESTING

The outer shell material will be thoroughly checked for strength and integrity by aggressive flexing of the material and the attempts to push a finger or thumb through the fabric. Any loss of strength or weakening of the material to the degree that the material can be torn with manual pressure will indicate signs of deterioration of the garment.

TRIM REFLECTABILITY

Material discoloration can indicate many types of possible damage including but not limited to heat degradation, UV damage and chemical contamination. Visibility markings can appear to the human eye to be undamaged when actually they have lost much of their ability to reflect. Retro-reflective properties are checked by following the flashlight test. This is performed by standing twelve metres from the trim being tested against new trim, holding a bright focused flashlight at eye level aiming the light beam at the two samples. If the reflective light from the trim being tested is substantially less than the light reflective of the new trim, this will indicate damage to the trim.

THREAD STRENGHT

Using the outer or inseam of the garment, one seam stitch shall be opened approximately five inches in length. A pulling device is then applied to both sides of the seam, the thread should be able to withstand manual exertion force without breaking the thread.

MOISTURE/THERMAL LIGHT EVALUATION

This evaluation method applies to liner composites of the protective garment. Specific areas of the body panels that shall be evaluated include the upper back, shoulders, underarms, sleeves, crotch and leg area. The apparatus used to perform the light evaluation will consist of a strong light source that will show the changes in density of the liner materials when viewed. The evaluation is conducted by separating the liner from the outer shell, positioning the light source near the moisture barrier so that light passes through the moisture barrier and then through the thermal barrier.

Appendix 3

Results of Microbiological Testing with Pictures

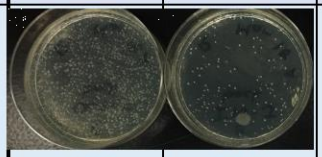
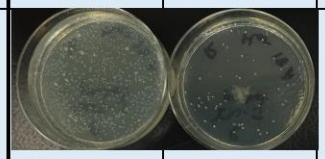
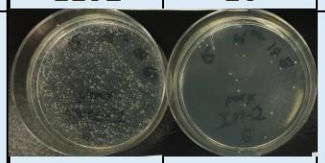
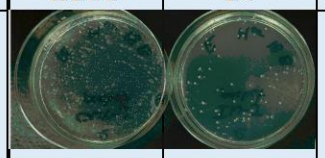
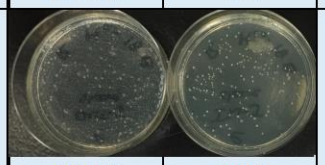
Table 2		*E.coli*		Gear Testing				
Experimental Conditions					**Experimental Results**			
Test #	Diluted cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
1	no	no	490	S	 1492	179	88.0	**94.1**
2	no	no	490	S	 532	66	87.6	
3	no	no	490	S	 1152	16	98.6	
4	no	no	536	S	 2208	26	98.8	
5	no	no	536	S	 2400	93	96.1	
6	no	no	536	S	 4056	190	95.3	

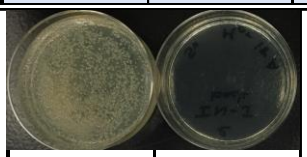
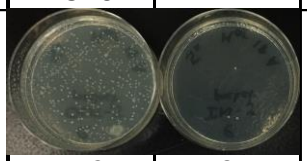
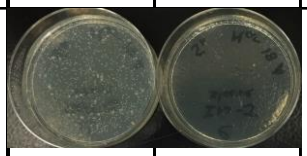
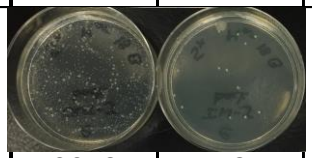
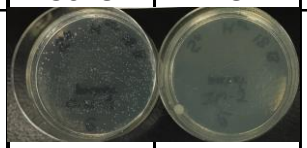
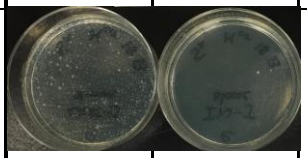
Table 2		*E.coli*		Gear Testing				
Experimental Conditions					**Experimental Results**			
Test #	Diluted cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
7	yes	no	490	S	 1920	1	99.9	**99.7**
8	yes	no	490	S	 552	3	99.5	
9	yes	no	490	S	 716	3	99.6	
10	yes	no	536	S	 3048	18	99.4	
11	yes	no	536	S	 1192	3	99.7	
12	yes	no	536	S	 2672	2	99.9	

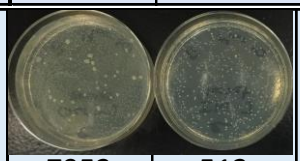
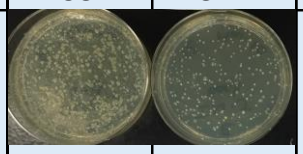
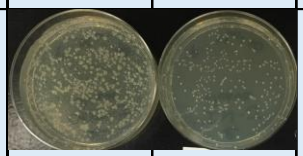
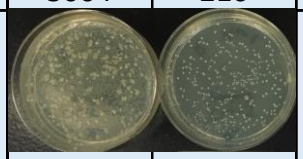
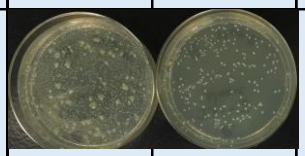
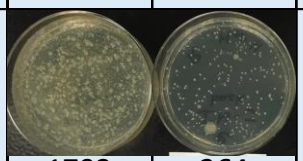
Table 2		*E.coli*		Gear Testing				
Experimental Conditions					**Experimental Results**			
Test #	Diluted cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
13	no	no	86	F	 7952	512	93.6	**86.3**
14	no	no	86	F	 3344	296	91.1	
15	no	no	86	F	 3664	216	94.1	
16	no	no	107	F	 3312	316	90.5	
17	no	no	107	F	 2848	118	95.9	
18	no	no	107	F	 1792	264	85.3	
19	no	no	120	F	 108	50	53.7	

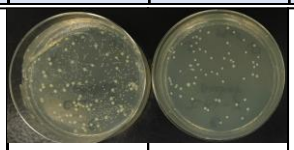
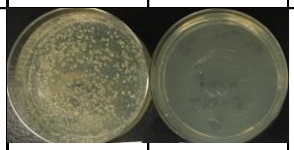
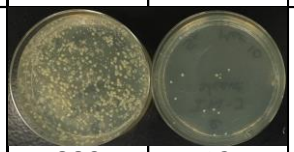
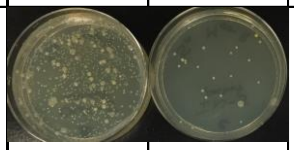
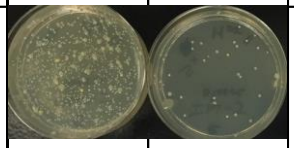
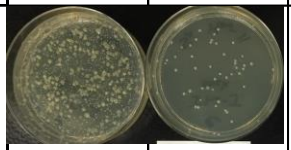
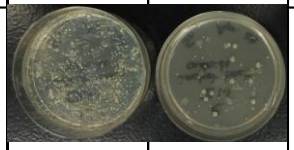
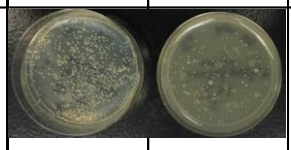
Table 2		*E.coli*		Gear Testing				
Experimental Conditions					**Experimental Results**			
Test #	Diluted cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
20	yes	no	86	F	 644	78	87.9	**91.4**
21	yes	no	86	F	 1440	1	99.9	
22	yes	no	86	F	 880	12	98.6	
23	yes	no	107	F	 864	26	97.0	
24	yes	no	107	F	 952	45	95.3	
25	yes	no	107	F	 1520	58	96.2	
26	yes	no	120	F	 400	52	87.0	
27	yes	no	120	F	 588	179	69.6	

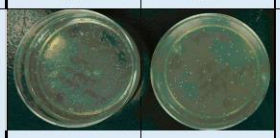
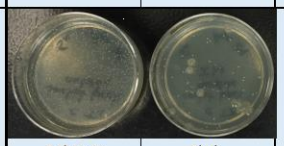
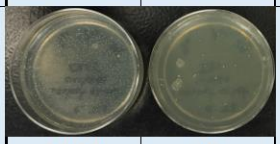
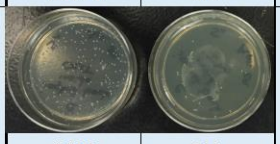
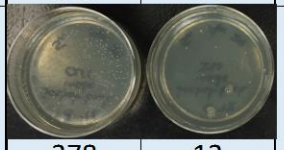
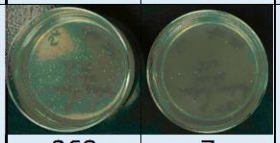
Table 2		*E.coli*		Gear Testing				
Experimental Conditions					**Experimental Results**			
Test #	Diluted cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
28	yes	yes	15	F	 91	17	81.3	**90.0**
29	yes	yes	15	F	 82	25	69.5	
30	yes	yes	30	F	 1084	116	89.3	
31	yes	yes	30	F	 1000	111	88.9	
32	yes	yes	43	F	 1256	90	92.8	
33	yes	yes	43	F	 1424	19	98.7	
34	yes	yes	30	F	 234	24	89.7	
35	yes	yes	30	F	 321	14	95.6	
36	yes	yes	43	F	 378	12	96.8	
37	yes	yes	43	F	 268	7	97.4	

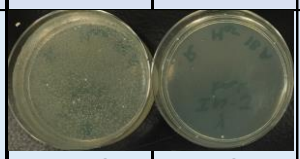
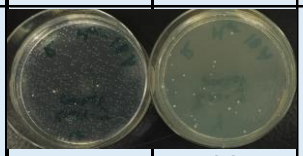
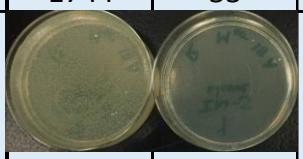
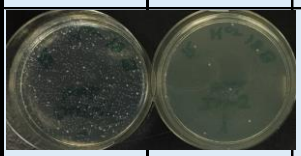
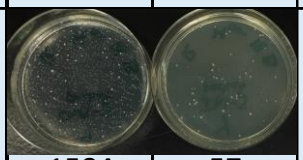
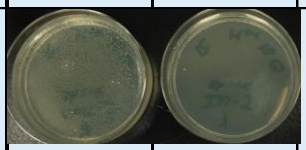
Table 3		*S. cerevisiae*			Gear testing			
Experimental Conditions					**Experimental Results**			
Test #	Diluted Cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack, S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
1	no	no	490	S	 4112	10	99.8	**99.0**
2	no	no	490	S	 1744	33	98.1	
3	no	no	490	S	 5088	3	99.9	
4	no	no	536	S	 1832	7	99.6	
5	no	no	536	S	 1584	57	96.4	
6	no	no	536	S	 6064	1	100.0	

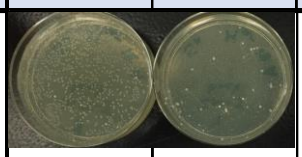
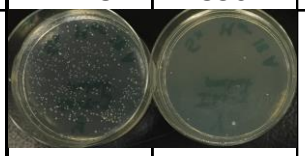
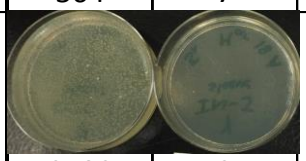
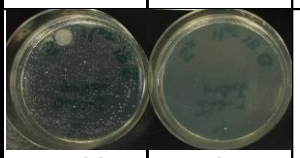
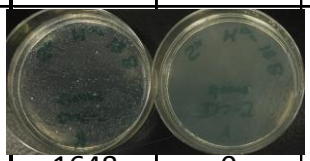
Table 3		*S. cerevisiae*			Gear testing			
Experimental Conditions					**Experimental Results**			
Test #	Diluted Cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack, S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
7	yes	no	490	S	 1128	356	68.4	**94.5**
8	yes	no	490	S	 564	7	98.8	
9	yes	no	490	S	 2432	2	99.9	
10	yes	no	536	S	 1920	1	99.9	
11	yes	no	536	S	 1168	3	99.7	
12	yes	no	536	S	 1648	0	100.0	

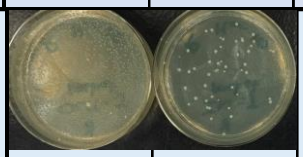
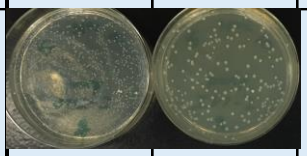
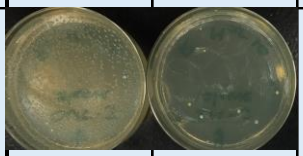
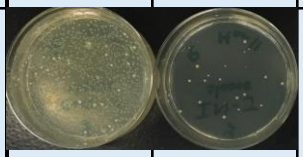
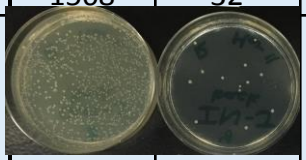
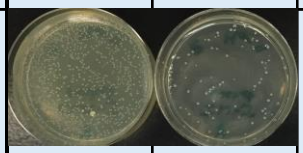
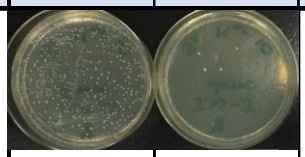
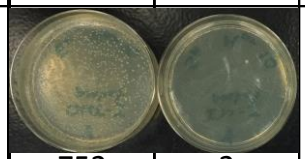
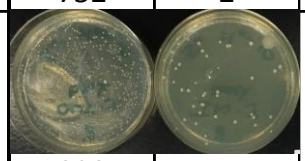
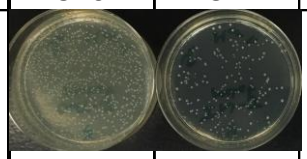
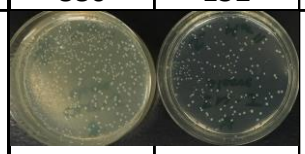
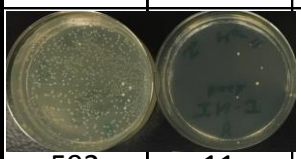
Table 3		*S. cerevisiae*			Gear testing			
Experimental Conditions					**Experimental Results**			
Test #	Diluted Cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack, S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
13	no	no	86	F	 2936	53	98.2	**93.8**
14	no	no	86	F	 880	184	79.1	
15	no	no	86	F	 1312	8	99.4	
16	no	no	107	F	 1568	32	98.0	
17	no	no	107	F	 696	14	98.0	
18	no	no	107	F	 928	92	90.1	

Table 3		*S. cerevisiae*			Gear testing			
Experimental Conditions					**Experimental Results**			
Test #	Diluted Cultures	Air-blowing	max O_3 ppm	Single jacket / Full rack, S/F	Control, cfu (OUT)	Test, cfu (IN)	Microbial kill rate, %	Average microbial kill rate, %
19	yes	no	86	F	 496	6	98.8	**92.0**
20	yes	no	86	F	 752	2	99.7	
21	yes	no	86	F	 920	51	94.5	
22	yes	no	107	F	 880	152	82.7	
23	yes	no	107	F	 648	140	78.4	
24	yes	no	107	F	 592	11	98.1	