Impact of CO2-Based Cleaning Technology on Firefighter Turnout Gear: Outer Shell Performance after 30 Cleaning Cycles

Nelson W. Sorbo, Ph.D., Cool Clean Technologies, LLC.

Background

CO2-based cleaning technology is an effective decontamination technology that is now available for advanced and specialized cleaning of firefighter gear, including coats, pants, hoods, gloves, leather boots, and other related clothing articles. Emergency Technical Decon (ETD) offers this innovative cleaning technology at its Eagan, MN facility and soon to be opening a service site in Oregon. Based on third party cleaning verification testing at UL in accordance with NFPA 1851 test methods and requirements, the CO2 based cleaning system has generated outstanding cleaning and decontamination results for semi-volatile organic compounds (SVOCs), heavy metals, and bacteria. Another key feature of this technology is minimizing its impact on the performance properties of these articles from repeated cycles of cleaning and decontamination. This paper summarizes results that show no significant effects on an outer shell material after multiple cleanings in the CO2 cleaning systems relative to other industry standard cleaning processes used today.

Test Methodology

The suggested annex procedures provided in NFPA 1851 in A.7.3.7.3 where panels measuring 26” x 26” of outer shell material with hemmed edges (see Figure 1) were used for evaluating changes in outer shell performance properties after 30 cycles of CO2 cleaning. For this testing, the panels were constructed of a 7.5 osy (ounces per square yard) 60/40 Kevlar/PBI twill. Some samples included seams, trim, and labels to also evaluate the effects of repeated cleaning on these components. Each panel was photographed and combined with other clothing and ballast material to provide a representative load weighing approximately 35 lbs. Note that because the articles processed are dry at cycle completion, each-cycle method represents both cleaning and ‘drying’ of the articles. The typical process cycle length is 60 minutes. As part of this methodology, test samples were examined after each set of ten (10) cleaning cycles to observe and measure certain properties related to outer shell cleaning durability. These included water droplets spread on the material surface at different locations, the measurement of color coordinates using a spectrophotometer, and appearance of samples having trim and labels components. At the completion of all 30 cleaning cycles, the samples were shipped to UL for assessment.

NFPA 1971 tests conducted by UL on the outer shell samples included:

- Breaking strength (ASTM D5034)
- Tear resistance (ASTM D5587)
- Seam strength (ASTM D1683)
- Water absorption resistance (AATCC 42)
- Cleaning shrinkage (AATCC 135 (1, V, Ai)
- Flame resistance (after flame, char length – ASTM D6413)
- Thermal protective performance (TPP) – (ISO 17241)
- Total Heat Loss (THL) – (ASTM F1868, Pr. C)

Both TPP and THL measurements were made on the composite of the selected outer shell with biocomponent pTFE/woven Nomex moisture barrier and a 7.0 osy Lenzing, Kevlar, Nylon with needle punch nonwoven thermal barrier.

Figure 1 – Example of test sample panel that was evaluated

Internal Durability Assessment Results

Observations from the placement of water droplets on the outer shell surface showed no change over the three different sets of 10 cleaning cycles (see Figure 2) when compared with unwashed outer shell samples.

No diminishment of trim brightness was observed when a flashlight was directed towards the trim portion of the sample under dark conditions.

Spectrophotometric measurements did not show any significant changes between unwashed and successively cleaned outer shell samples (see Figure 3).

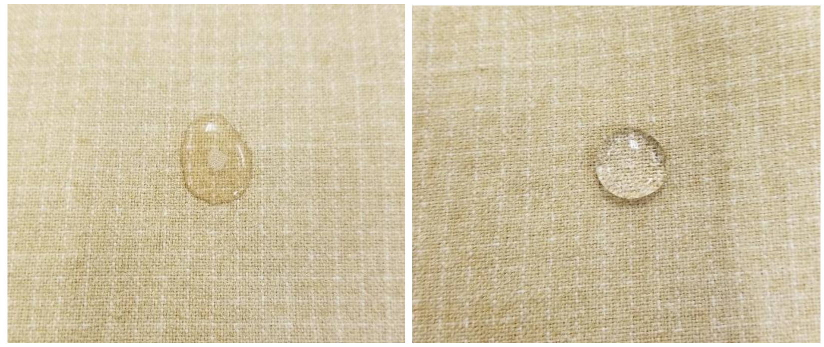

Figure 2 - Appearance of Applied Water Droplets on Outer Shell Sample; Before any cleaning – left, After 30 Cleaning Cycles - right

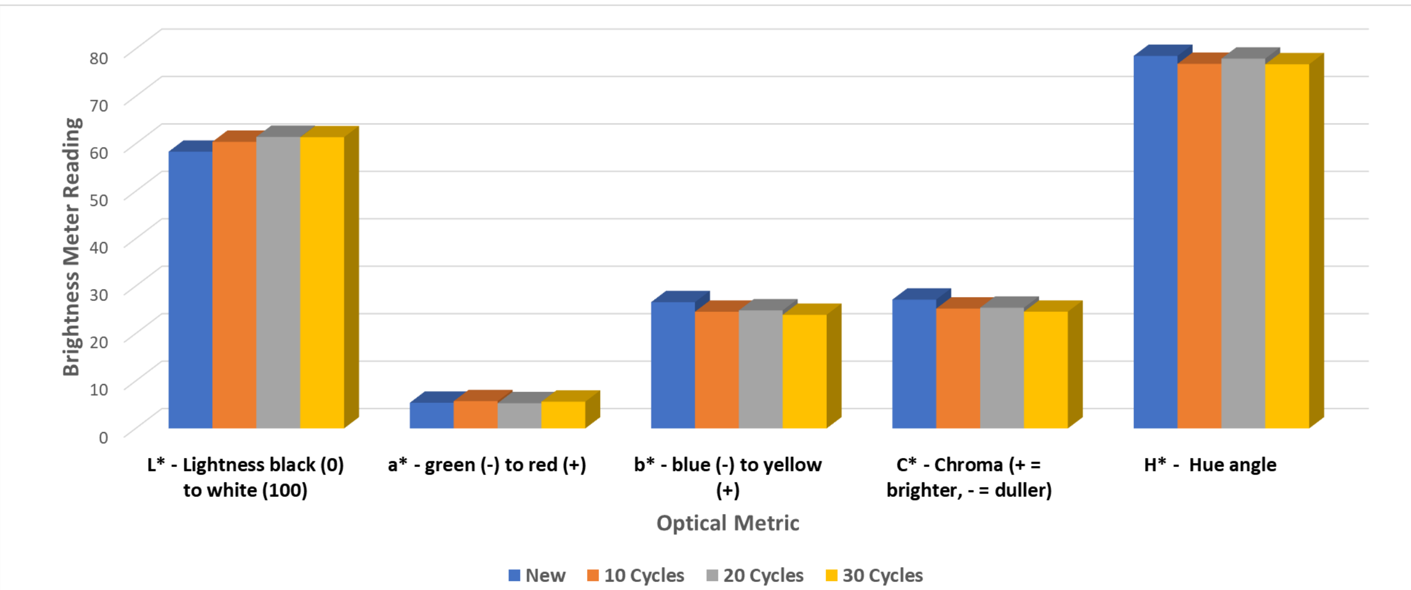

Figure 3 – Color Coordinates for Outer Shell Samples Before and After Cleaning (Individual color parameters pertain to brightness(L) and specific ways by which color is quantified (a*, b*, C*, H*))*

UL Durability Test Results

The results of the UL tests are summarized in Table 1 and show **insignificant** changes to key outer layers of the turnout gear, which include the NFPA 1971 requirements, baseline values for new (uncleaned) samples, results measured after 30 cycles of CO_2 cleaning, and the percent change for the multi-cleaned samples from the baseline values.

Breaking Strength, Tear Resistance and Shear Strength

The breaking strength of a fabric also can be called tensile strength, which refers to the maximum tensile force when the specimen is stretched to break. Warp and fill (also called weft) refer to the orientation of woven fabric. The warp direction refers to the threads that run the length of the fabric. The fill, or weft, refers to the yarns that are pulled and inserted perpendicularly to the warp yarns across the width of the fabric. Examination of the results in Table 1 show that the breaking strength, tear resistance and shear strength showed minimal changes to their baseline values after 30 CO_2 process cycles. And for three cases, the 30 CO_2 cycles increased these values.

Thermal Protective Performance (TTP) and Total Heat Loss (THL)

TPP defines the thermal insulation of structural firefighter protective clothing. IAFF worked to identify appropriate levels of heat insulation in clothing by investigating fireground conditions and determining needed escape time. This research led to the current TPP rating of 35 that has been the minimum standard for firefighter clothing since its introduction in 1986.[1] The THL of a garment is designed to quantify the evaporative heat transfer through structural garments. The TTP and THL values presented of samples processed 30 times in Table 1 showed **insignificant** changes compared to their baseline values.

Water Absorption Resistance and Cleaning Shrinkage

Water absorption resistance quantifies the degree of 'water proofing' present on the sample. As shown in Table 1, the water absorption resistance after 30 cleaning cycles doubled compared to the baseline value but was about 50% of the requirement. The cleaning shrinkage values in warp and fill directions showed only 2% change compared to baseline values.

Afterflame and Char Length

Afterflame time is the time during which the material continues to flame after the ignition source has been removed or extinguished. Char Length is the length in inches of fabric destroyed by the flame. The occurrence of melting or dripping, if any, is recorded. Five tests are performed, and the results are averaged and reported as the final test result. The data reported in Table 1 shows afterflame and char length in both the warp and fill directions well below the action levels.

Table 1 – UL Durability Test Results after 30 CO2 Cleaning Cycles

Property	Requirement	Units	Baseline	Cleaned 30X	Percent Exceeding Requirement After 30 Washes
Breaking Strengh - Warp	623	N	1399	1374	121%
Breaking Strength - Fill	623	N	1387	1566	151%
Tear Resistance - Warp	100	N	224	209	109%
Tear Resistance - Fill	100	N	205	208	108%
Shear Strength	667	N	821	868	30%
TPP	>= 35	cal/cm^2	44.5	46	31%
THL	>=205	W/m^2	214.7	218.2	6%
Water Absorption Resistance	<= 15	%	4	8	47%
Cleaning Shrinkage - Warp	<= 5	%	na	na	60%
Cleaning Shrinkage - Fill	<= 5	%	na	na	60%
Afterflame - Warp	<=2	sec	0.2	0.2	90%
Afterflame - Fill	<=2	sec	0.2	0.1	95%
Char length - Warp	<=100	mm	10	12	88%
Char length - Fill	<=100	mm	10	13	87%

Conclusions

The CO2 cleaning process not only yields excellent cleaning and decontamination efficacy based on its cleaning verification results, but these additional data shows that the process does NOT adversely impact the outer layer of the turnout gear in any meaningful way. Those interested in better cleaning and toxin removal without damage to their gear should consider this option.

[1] Stull, J.O and G.G Stull, Fundamentals of thermal protective performance; FireRescue1 – 17 May 2012 https://www.firerescue1.com/fire-products/turnoutgear/articles/fundamentals-of-thermal-protective-performance-65RIkJf2fzQv7Wm6/