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Fire and Ice: A Soot Removal Technique Using Dry Ice Blasting

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To say that for destruction ice
Is also great
And would suffice
— Robert Frost[1]

Introduction

A welder's spark touched off the attic fire in the Sevier County Recorders Office (Richfield, Utah, USA) on 2 May 2006, igniting a blaze that ripped through the crawl space and greedily consumed the building's paper-backed insulation. The fuel readily spent, the fire burned itself out 15 minutes later, sparing the structure but coating everything below the rafters with fine, powdery soot.

This carbonaceous residue filtered down through the ceiling tiles and settled on everything in the offices below, including the historic courthouse record books stored horizontally on metal rolling shelves within the vault. Approximately 300 nineteenth- and twentieth-century full-leather spring-back stationers' bindings, many covered in protective white canvas jackets, were untouched by the fire but impregnated with a layer of soot and reeked of smoke.

The Problem

Among commercial disaster firms in the U.S., the current standard for removing soot's grim, grey residue from books is to wipe down the covers with a "chemical," or natural rubber sponge,[2] and then "ozonate" the books to eliminate the residual smoky odor. This approach leaves much to be desired. While the sponge does trap much of the fine, carbon-laden particulate in its tan, rubbery surface, it also quickly fills with residue. Recovery workers must constantly rotate their sponges to expose unused areas to the grime and throw spent sponges away as they are not readily cleaned. The wiping process

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itself forces some of the fine, dark soot particles back into the interstices of the material being cleaned, especially when that surface is as porous as the open weave of canvas book jackets.

Trapped soot becomes more intractable with time as the polymerized and dehydrogenized byproducts of the fire chemically bond to their surroundings.[3] The friction of wiping also causes some portion of the sponge's soft rubber to transfer to the book's surface, trading one unstable residue for another.[4] Finally, exposing "cleaned" books to ozone to reduce the residual smoke odor causes further degradation. A strong oxidizer, ozone aggressively breaks down paper, cloth, leather, and adhesives while it decomposes the organic components of the smoke–a highly undesirable tradeoff for books of historic significance mandated by law to be maintained in perpetuity.

In short, soot is an extremely tenacious material to remove. Unlike dust, it is a solid/liquid residue composed of carbon suspended in an oily foundation of partially consumed combustion byproducts. The carbon within these tar droplets is so fine–1 μm in diameter, or approximately 1/50 the width of a human hair–it is readily dispersed by the "pressure and buoyancy created by the heat of the fire" and aerodynamic conditions such as "stack effect, wind pressures, the building geometry and its barriers (such as walls and floors), and ventilation practices."[5] Soot's fine powder coats every exposed surface, penetrating even the tiniest crevices and crannies, anchoring the carbon with oily tars where it lands. Removal attempts by wiping, even with an absorbent, fleshy material such as the above-mentioned natural rubber sponge, inevitably smears whatever soot does not bond to the sponge, compressing and embedding the diminutive, greasy specks further into the surface and making them more difficult to remove. As soot ages, it chemically cross-links to the material it is in contact with, making immediate cleanup the optimal course of choice.

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Vacuuming with a high efficiency particle (HEPA) filter in tandem with manual wiping can help, but alone it is actually less effective than wiping with an absorbent material. In the 1997 Saskatchewan (Canada) Museum fire, for example, Spafford-Ricci and Graham report the soot removal protocol used for book cleaning included an initial vacuuming of the book's binding, followed by a separate vacuuming of the text block. Care was taken not to touch the surface of the books with the vacuum's nozzle as this contact would push soot into the woven fabric of the bookbindings. After vacuuming, the second phase of this cleanup included mechanically wiping the book's surface with rubber sponges or Webril® Wipes (a felted, nonwoven 100% cotton pad commonly used in the printing industry for non-abrasive cleaning of printing plates).[6]

Eliminating residual smoke odor from objects following soot removal is the next thorny problem. In addition to simply spraying scents to mask the odor, at present, three approaches predominate within the fire recovery industry: chemical deodorizing, thermal deodorizing, and ozone treatment. Unfortunately, all three have serious drawbacks when dealing with cultural heritage material.

Chemical deodorizing eliminates odors through a chemical reaction occurring when the chemical fumes of the product come into contact smoke residue. These deodorizers come in a wide range of extremely pungent fragrances designed to "purify" air spaces ranging in size from 1,000-20,000 cubic feet. Some of these formulations are applied as a thermal fog; others are simply diffused from the source container. The long-term effects on cultural property of these proprietary formulations have not been analyzed. More broadly, however, deleterious effects from gaseous pollutants–particularly sulphur dioxide (SO_2),oxides of nitrogen (NO_x), and ozone (O_3)–have been well documented with paper, leather, textiles, dyes, pigments, inks, adhesives, and photographic film.[7] Introduction of gaseous chemicals for deodorizing purposes is not recommended until

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their long-term effects can be tested.

Thermal oxidation deodorizing is a second approach used to eliminate volatile organic compounds (VOCs) from the ambient air. Essentially, the system is an afterburner that draws workplace air through a combustion chamber where VOCs are incinerated.[8] Principally used in industrial settings to deal with gaseous byproducts from petrochemicals, printing, paint, food, sewage and waste treatment, application of this technology to reduce smoke odors emanating from heritage materials has not yet, to my knowledge, been attempted.

Finally, ozone is commonly used to treat smoke odors in affected household and office objects. This treatment includes creating copious amounts of O_3 with an electric ozone generator and sequestering the smoke-damaged material in a confined space with the gas. Unfortunately, while O_3 eliminates smoke odors, in high concentrations O_3 is both harmful to human health[9] and an aggressive oxidizer known to deleteriously impact a wide range of cultural heritage materials, as noted above.[10] Hence, despite its common use for less significant objects, O_3 should be avoided.

At present, the only safe approach to removing smoke odors from cultural material is to isolate the smoke-tainted objects in a room with an operating air purification system that contains activated carbon, zeolite, and/or potassium permanganate filtration. Continuously re-circulating filtered air past the objects will reduce smoke's lingering odor gradually over time if the material can be well exposed to the air flow. An inexpensive alternative is to place small amounts of material in relatively airtight enclosures (such as a large, sealed plastic garbage bag) in close proximity to large quantities of exposed baking soda. Either approach may take two to three months to work with the key being to exposure the impacted material to the absorbent media. Michael

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Trinkley reports, "Records which survived the 1906 San Francisco fire and are today in the [U.S.] National Archives still smell strongly of smoke–over 90 years latter,"[11] a condition possibly exacerbated by the lack of air exchange.

Sevier County

In the aftermath of the Sevier County Recorders Office fire, a non-damaging alternative to the current cleaning options seemed desirable. Invited by the responsible commercial recovery company to serve as a consultant,[12] I suggested dry ice blasting as an interesting possibility. Dry ice blasting has proven its utility in a variety of industrial applications over the past decade including dispatching paint from decorative metalwork; cleaning dirt from brick, granite, marble, onyx, or other stone materials; stripping built-up wet or dry ink from printing presses; removing fused dust from electrical turbines, generator windings, and transformers; and remediating mold from building interiors.[13] Additionally, the system is portable and can be powered by an electric generator, adding significantly to its merits since the County Recorder would not permit the damaged books to leave the Recorders Office.

The process works by shaving solid blocks of dry ice (frozen CO_2) into granules ranging in size from the diameter of sugar to the shape of rice, depending upon the application. These granules are propelled in a compressed air stream of 30-300 PSI against the surface to be cleaned. Dry ice blasting is considered completely non-abrasive when used on surfaces harder than frozen CO_2, but can be used to "antique" wooden siding by differentially abrading the softer, pithy wood and leaving the grain. Frozen CO_2 pellets emerge from the nozzle at -78°C, dramatically lowering the surface temperature of the media being cleaned and causing incremental shrinkage. This contraction occurs simultaneously as the CO_2 sublimates to its gas phase, expanding approximately 80-800 times its original size. These multiple forces–contraction due to cold, turbulence caused

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by rapid sublimation, and pressure from the compressed airstream–occur simultaneously. As the minute dry ice particles penetrate the interstices of the media being cleaned, the CO_2 sublimates leaving only "dirt" as the residual byproduct.

As a preparatory step to attempting to remove the soot from Sevier County's record books using dry ice blasting, a couple of expendable modern publishers' bindings were first tested. With the dry ice crystals ground sugar-fine, the PSI set to a minimum (30 PSI), and the compressed air nozzle held far enough from the books to prevent abrasion (15-18 inches), a local applicator[14] expertly cleaned these mock ups while I monitored the effect. The applicator played the machine's[15] spray of CO_2 granules in a steady sweep across the bindings, his experience essential to preventing damage. The technique worked flawlessly, but we also discovered that too long a focus on one spot, or allowing too little distance between the nozzle and book's surface, could remove dye from the cloth or gold foil stamping from the cover. We also found that older, hand tooling (both hand stamping and decorative lines run with a roll) presented no problem in the cleaning, suggesting that modern titling on mass market books is far more friable than earlier handwork. Similarly, directing the dry ice nozzle directly at the edges of the text could abrade the paper surface slightly, so the situation was remedied by focusing the nozzle's aim specifically at the board edge so only the peripheral dry ice spray played over the fore-edge, head, and tail. By firmly clamping the text closed and minimizing direct pressure to the paper edges the text was undamaged by the cleaning process.

We then compared dry ice blasting with two other forms of soot removal using actual record books; wiping down part of a book with a natural rubber sponge, and vacuuming another section with a HEPA filter. As described earlier, the rubber sponge proved reasonably effective although it left some visible soot residue. The HEPA-vacuuming proved far less effective than the sponge, underscoring the bonding strength of the soot, even a single week after the fire. Dry ice blasting proved the most effective of the three methods and caused no detectable abrasion. In addition to removing the soot, the cleaning eliminated years of embedded hand grease as well as a piece of pressure sensitive tape along with the discolored adhesive residue beneath it. As a further test, each cleaned object was sequestered overnight in a sealed box to determine how much residual smoke odor remained. Again, dry ice blasting surpassed the two other cleaning methods.

The technique also proved to be far faster than wiping down the books using rubber sponges. The canvas-covered bindings took longer to clean than books with exposed leather, but on average, six books were dry ice blasted per hour (50 hours total). Jayrene Nielsen, the County Clerk, expressed her amazement at the end result. She claimed the books had never looked so clean. While building repairs progressed, the commercial recovery company, leery of a slight residual smoke odor, packaged the cleaned volumes for storage in boxes containing a chemical deodorizer. In direct discussion about this with the County Clerk, Ms. Nielsen agreed to remove the deodorizers from the boxes, claiming she actually preferred the smell of smoke to the noxious deodorant! She also believed the smoke odor was rapidly dissipating as the books aired out.

As with any new conservation technique, dry ice blasting will surely prove to have its limitations. Based on the excellent results at Sevier County, however, it appears the technique has great promise for addressing certain problems and should be considered as a viable option as the situation demands. Additionally, further safeguards or modifications to the approach described herein may be warranted. Great care should be exercised, for example, when testing dry ice blasting's effectiveness for removing soot from rare books, as the age and variability of the material involved might well present numerous challenges. While dry ice blasting has been successfully used for mold

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remediation on building surfaces, its application to removing mold from damaged bindings has yet to be investigated. Again, dry ice blasting seems to offer much promise, and additional reports and testing arising from future applications of the technology are encouraged.

Endnotes

1. Frost, Robert, "Fire and Ice," *Collected poems, prose, and plays* (New York: Library of America, 1995): 204.

2. The principle source for natural rubber sponges (stock #60142) is: Quality Rubber Co, 415 Metallic Lane, Sedalia, MO 65301, USA. Tel. 660-826-4641; toll free, 800 597-9947.

3. On the long-term problems of soot removal from cultural property, see: Roberts, Barbara, et al. "An Account of the Conservation and Preservation Procedures Following a Fire at the Huntington Library and Art Gallery," *Journal of the American Institute for Conservation* 27:1 (Spring 1988):1-31; Spafford-Ricci, Sarah, and Fiona Graham, "The Fire at the Royal Saskatchewan Museum, Part 1: Salvage, Initial Response, and the Implications for Disaster Planning," *Journal of the American Institute for Conservation* 39, no 1, (Spring, 2000): 15-35, and, Spafford-Ricci, Sarah, and Fiona Graham, "The Fire at the Royal Saskatchewan Museum, Part 2: Removal of Soot from Artifacts and Recovery of the Building," *Journal of the American Institute for Conservation* 39, no 1, (Spring, 2000): 36-56.

4. See: E. Moffatt, "Analysis of 'chemical sponges' used by the commercial fire cleanup industry to remove soot from various surfaces," *IIC-CG (International Institute for Conservation - Canadian Group)* 17/3 (1991): 9-10.

5. McKinnon, Gordon P. And Keith Tower (eds.), *Fire protection handbook*, 14th ed. (Boston: National Fire Protection Association, 1976): 2-19; 2-27.

6. Spafford-Ricci and Graham, "The Fire at the Royal Saskatchewan Museum, Part 2: 48-49.

7. Committee on Preservation of Historical Records, National Materials Advisory Board, *Preservation of historical records* (Washington, D.C.: National Academy Press, 1986):11-31; Baer, Norbert S., and Paul Banks, "Indoor air pollution: Effects on cultural and historic materials," *International journal of museum management curatorship* 4 (1985): 9-20.

8. Thermal Oxidation Deodorizing Machine, by Osaka Gas Engineering Co., LTD, recovered from the world wide web 25 May 2006:

<http://www.gec.jp/CTT_DATA/AIR/AIR_5/html/Air-159.html>

9. U.S. Environmental Protection Agency, "Ozone Generators that are Sold as Air Cleaners: An Assessment of Effectiveness and Health Consequences," recovered from the world wide web 25 May 2006: <http://www.epa.gov/iaq/pubs/ozonegen.html>; U.S. Environmental Protection Agency, Air quality criteria for ozone and other photochemical oxidants, EPA-600/8-78-004 (Research Triangel Park, North Carolina: U.S. Environmental Protection Agency, 1978).

10. Bogarty, H., K. S. Campbell, and W. D. Appel, "The oxidation of cellulose by ozone in small concentrations," *Textile research journal* 22 (1952): 81-83; Cass, Glen R., James R. Druzik, Daniel Grosjean, William W. Nazaroff, Paul M. Whitmore, and Cynthia L. Whittman. *Protection of Works of Art From Atmospheric Ozone*, (Los Angeles: The Getty Conservation Institute, 1989). Full text available at: <http://www.getty.edu/conservation/publications/pdf_publications/alpha_author.html>; Salvin, V. S., "Ozone fading of dyes," *Textile chemist and colorist* 1 (1969): 245-251. Shaver, C. L., Glen R. Cass, and James R. Druzik, "Ozone and the deterioration of works of art," *Environmental science & technology* 17 (1983): 748-752.

11. [Trinkley, Michael], Chicora Foundation, "Fire" [ca. 16 June 2003], recovered from the world wide web 24 May 2006: <http://www.chicora.org/fire.htm>

12. Utah Disaster Kleenup (13081 South Minuteman Drive, Draper, Utah 84020 USA; tel. (801) 553-1010; <http://www.utdk.com/index.php>) is the commercial firm responsible for this recovery.

13. CO_2LDSWEEP Dry Ice Blasting, brochure (n.p; n.d, c. 2006).

14. This experimental work was conducted by Randell Heath, President, CO_2LDSWEEP Dry Ice Blasting (3612 Quail Point Road, Mountain Green, UT 84050 USA; tel. 801-876-5432; <info@coldsweep.com>). Mr. Heath is a certified mechanical engineer, and coincidentally, was originally born in Sevier County, UT. He served as a subcontractor to Utah Disaster Kleenup at the rate of US$ 150.00 per hour.

15. The dry ice blasting machine used was the Alpheus Precision Series TM Model T-2. This machine is quite mobile, measuring 14 in. x 22 in. x 20 in. (35.56 cm. x 55.88 cm. x 50.80; W x L x H) and weighing 110 lbs. (50 kg). It stores 12 lbs. (5.4 kg) of block dry ice, and produces a blast pressure range of 30 psi - 120 psi (2.1 bar - 8.3 bar).