Dry Ice Blasting

Dry ice blasting (DIB) is the use of solid or liquid CO_2 as an abrasive media when combined with compressed air; any type of abrasive blasting media inherently comes with health and safety measures, but the CO_2 media adds unique risks that require particular preparation. This article highlights health and safety protocols for dry ice blasting solid CO_2, as created by The Mariners' Museum and Park Batten Conservation Complex, by combining OSHA standards, information from published articles, and our own knowledge after hundreds of hours of dry ice blasting treatment. My coworkers and I have used dry ice blasting to remove degrading paint from cast iron cannons and to remove corrosion from wrought iron and copper alloy archaeological objects.

While the majority of the objects treated at this lab have been archaeological objects, the health and safety standards we used can provide guidelines for a variety projects and conservation laboratories. Although DIB is a versatile method that can be used to effectively clean and treat a variety of museum objects, this technique requires specific health and safety precautions. As a note, many of these guidelines are also applicable to liquid CO_2 blasting, however, as I have not worked with liquid CO_2, this article should not be used as a main guideline for these treatments.

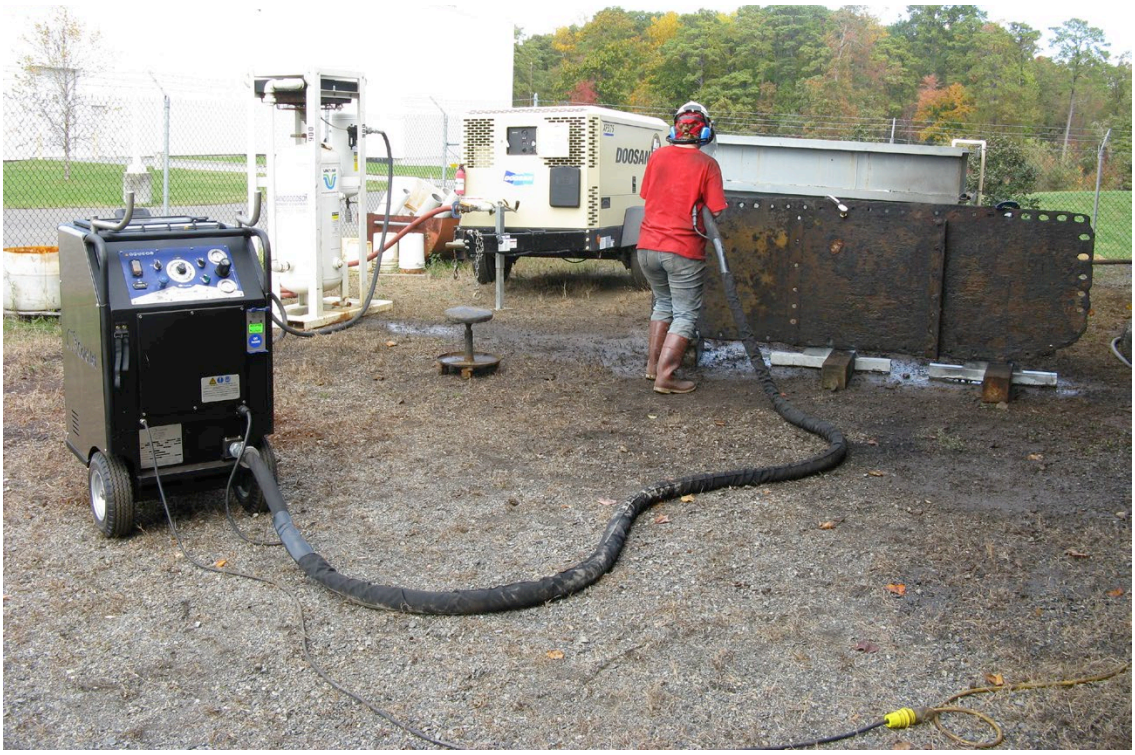


Figure 1. Mariners' staff member Kate Sullivan is seen treating an archaeological iron object, with DIB unit (left), the air dryer (middle), and air compressor (right). Image courtesy of The Mariners' Museum and Park.

Equipment

Dry ice blasting treatment requires a DIB unit, an air compressor, and an air dryer (based on the humidity of your working space), which can be rented directly from a dry ice blasting company or in combination with an equipment rental company (Fig. 1). A variety of dry ice blasting units exist with different air compression capabilities, nozzle sizes, and blasting capabilities (which should be thoroughly researched to select the best unit for your lab's needs). Once a unit is chosen, the appropriate dry ice (pellet or block form) can be purchased, as based on the requirements of the project and the unit. In most cases, dry ice only remains suitable for dry ice blasting treatment up to 4 days after production, as moisture in the air can crystalize on the CO_2 pellet surface, changing the hardness and strength of the material. The chosen unit will require a power supply, and this should be a part of the consideration for use.

Location

There are two main considerations when choosing a space to perform DIB treatments.

- As with most compressed gases, ventilation is of key importance to ensure the safety of the operator and any other person in the area.
- Treatment can cause re-deposition of material on nearby surfaces. For the safety of other artifacts and lab equipment, protection of these nearby surfaces needs to be considered.

Performing DIB treatment outside provides good ventilation and will allow for easier clean up. If working outside, a concrete or asphalt ground surface for your workspace is best. Gravel or dirt can be blown into the air by dry ice blasting, which can redeposit on the object, and cause abrasion to both the object and conservator. If working outside on a windy day, be sure to work upwind, so that debris and dust removed during treatment does not redeposit on you. Also, do not work outdoors on a rainy day, as most all of the required equipment is electric.

If working outside, remember that objects are fragile, but so are conservators! Protect yourself from the sun and dehydration. Take frequent breaks and be sure you are supplied with water and shade. Also be aware of ergonomic issues stemming from vibration from the unit's blast gun into the user's wrist and shoulders; dry ice blasting over a long period of time can cause fatigue in the arms, wrists, shoulders, and back, due to both the vibration and the handling of heavy equipment.

Frequent breaks and working with a partner are always required. A team of two makes for a better workflow, as one person can concentrate on treating the object, while the other monitors for safety hazards, photo-documents the process, and monitors the supply of dry ice in the blasting unit. When the person dry ice blasting becomes fatigued, the two can trade job assignments. Additionally, the second person can act as a spotter for the primary person, checking that PPE and safety equipment is in place and functioning properly. Designated shifts will also reduce the risk of human error accidents caused by fatigue.

If you are dry ice blasting indoors, ensure that your facilities provide adequate ventilation because DIB will release gaseous CO_2 into the environment. The ventilation provided by a fume hood, air extractor, or a simple open doorway should be enough to provide adequate air supply for most DIB treatments. However, if you are considering long hours of dry ice blasting indoors, or dry ice blasting treatment within an unventilated space, further precautions must be taken. Depending on the work area's ventilation and accessibility, supplied air may be required to safely conduct dry ice blasting treatment.

When working indoors, a CO_2 meter or O_2 meter is key for safe working practices. A CO_2 meter will alert you if gaseous CO_2 reaches an unsafe percentage level in the air. An O_2 meter will alert you if O_2 percentage in the air falls outside the safe zone for breathing (i.e., high CO_2 levels). Either will be sufficient to keep you safe during dry ice blasting treatment. However, both CO_2 and O_2 meters require periodic calibration and testing to ensure they are working properly. Always check the calibration date and test that the meter is functioning properly before beginning DIB treatment.

Additionally, when working indoors, consider the areas that might be reached by material that is removed from the artifact's surface during the process. Remove or cover any equipment or artifacts in the area to protect them from the material that is blasted from the surface of the artifact being treated.

Testing

Prior to any treatment, The Mariners' Museum and Park staff spend several hours testing samples to ensure that the DIB settings are sufficient for treatment, but also gentle enough to not damage the original surface of the objects. It is important to research potential DIB settings in relevant literature and consider doing your own testing before treatment. See the dry ice blasting resources list at the end of this document to begin such research.

Moreover, any object to be treated with dry ice blasting should be tested for hazardous materials, such as heavy metals. For example, lead especially can be found in old paint coatings on objects. XRF is the most straightforward method for testing for hazardous heavy metals, but other less expensive testing methods are available, such as one-use lead test kits. If any hazardous materials are present, it is not advisable to treat the object with abrasive cleaning methods like DIB, as this will release small particles of the material into the air. If DIB is conducted on

objects with hazardous materials, extensive PPE will be required for the staff members, including but not limited to full-face masks with the appropriate cartridges and disposable Tyvek suits.

Set Up and Workflow

Remember that as dry ice blasting can easily remove corrosion and coatings and can also be damaging to any delicate or degraded parts of an object.

- If working on an object that has degraded or fragile areas, consider a temporary consolidant or protective cover. The orientation of an object, polyethylene foam support, or wrappings can make all the difference to a fragile section. Also, secure objects to a working table or sawhorses to prevent movement due to high psi during treatment. This can be done with weights or clamps, depending on the needs of the object (Fig. 2).
- In the case of a utilitarian object with many working parts, anticipate potential disassembly during dry ice blasting treatment. Document the different components and be prepared to disassemble the object or parts of the object as dry ice blasting proceeds. Pre-number various components and have object number access tags ready, and photo document all components prior to DIB.

Dry ice will be delivered in a larger cooler or tote. Be sure to have the appropriate materials to handle CO_2 movement from cold tote to blasting unit:

- Dry ice rated protection gloves should be worn to protect your hands (Fig. 3).
- A scoop should be used to move pellets from tote to blasting unit, and ice block tongs should be used to move ice blocks.
- While smaller blocks may be moved by hand, heavier blocks should be moved with tools, such as ice tongs, for safety.

Remember that despite insulation from the cooler/tote, dry ice will sublime and release CO_2 gas into the tote. CO_2 gas is denser than air and will flow to the bottom of its container. However, keep the presence of CO_2 gas in mind and be aware of your surroundings as you remove dry ice from the container.

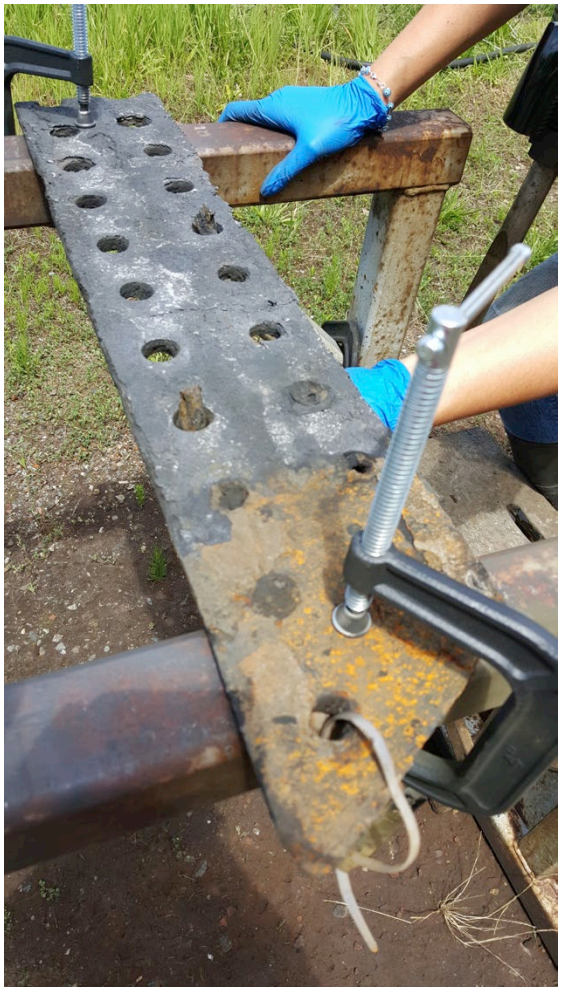


Figure 2. An archaeological iron object is held in place using two clamps and attaching the object to saw-horses, so that the object does not move during dry ice blasting. Image courtesy of The Mariners' Museum and Park.

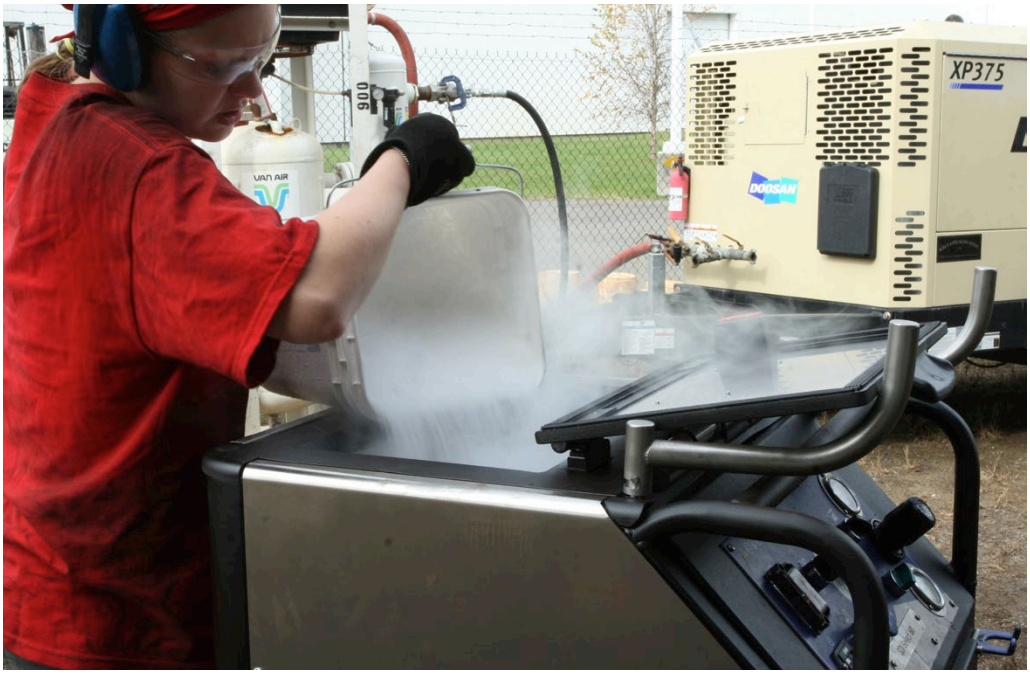


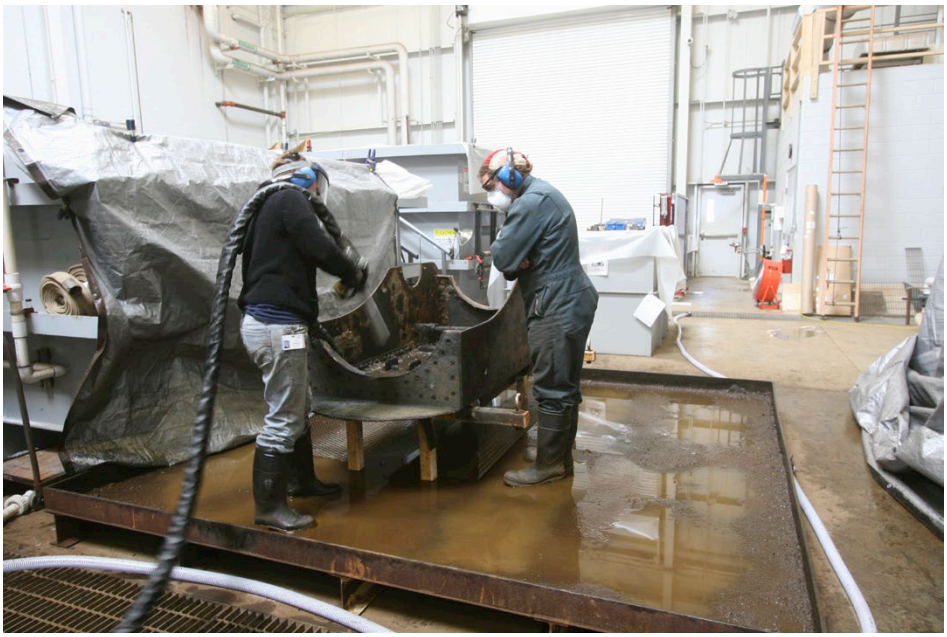
Figure 3. Mariners' staff member Kate Sullivan is seen pouring dry ice pellets into the blasting unit, wearing the appropriate protective equipment Image courtesy of The Mariners' Museum and Park.

Personal Protective Equipment

Before selecting PPE, consider the clothing to be worn when performing the treatment. Although there is no CO_2 residue, there is often residue/dust of what was removed from the object. Especially when dealing with archaeological objects or coating removal, you will want to consider wearing durable clothing with long sleeves and boots, to protect your skin from abrasion. (Fig. 4)

Respiratory Protection

The abrasive process will remove dirt, corrosion, concretion, and coatings from the surface of the object and send them into the air as small particles. At a minimum, wear a dust mask (N95 particulate respirator) to protect yourself from inhalation of particles while dry ice blasting or use an air purifying respirator with P100 cartridges. Additionally, consider using barriers and curtain walls to isolate the blasting operation from other parts of the lab. This protects other workers as well as objects and equipment in the lab from dust. (Fig. 5) Use ventilation systems as applicable to remove both the fine debris and gaseous CO_2 from the lab environment. If you are removing coatings from an object using a combination of solvent and dry ice blasting, wear the appropriate air purifying respirator for the solvent being used, such as a half- or full-face respirator, with the appropriate chemical cartridges. Remember that before using any air-purifying respirator (including N95 masks), fit tests must be performed by licensed professionals to ensure staff safety.



Hearing protection

Hearing protection is required and will vary with the psi used in the procedure. Use a sound level meter to determine the noise level produced by equipment and select hearing protection based on the OSHA standard of a time-weighted average (TWA) noise level of 85 decibels or higher over an 8-hour work shift.

In our experience, dry ice blasting between 150-100psi produces 105-112 dBA. Noise producing 105-112dBA requires a double level of earing protection, both earplugs and over the ear protection (ear defenders). Less than 100psi may only require one of these protective methods, but unless your institution is using a sound meter to measure decibel levels, wearing earplugs and ear defenders for maximum safety is recommended. Research the decibel protection levels for your hearing protection equipment and ensure it will be suitable for your work.

Consider where your working area is located in relation to others in the museum. The noise may disturb other labs or may require hearing protection for others in the lab or nearby. It may be ideal to perform dry ice blasting treatment outside so

Figure 4 (above). Mariners' staff member Laurie King is seen wearing all of the appropriate PPE for dry ice blasting treatment: ear protection, eye protection, respirator mask, cold protection gloves, long sleeves, trousers, and boots. Image courtesy of The Mariners' Museum and Park.

Figure 5 (left). Mariners' staff Elsa Sangouard and Will Hoffman examine treatment progress. In the background, tarps have been placed over tools and equipment to keep them clean during DIB process. Image courtesy of The Mariners' Museum and Park.

that the noise from the treatment does not disturb others in your museum. If this is not possible, follow OSHA guidelines to ensure that both staff and visitors are safe from noise damage.

Eye Protection

At minimum, wear impact-resistant safety glasses or goggles to protect your eyes against small particles blown into the air by dry ice blasting. If working with larger objects, or archaeological objects with a significant amount of material to be removed from the object surface, it is highly recommended to wear an impact-resistant face shield in addition to safety glasses, to protect the face from abrasion and provide superior eye protection.

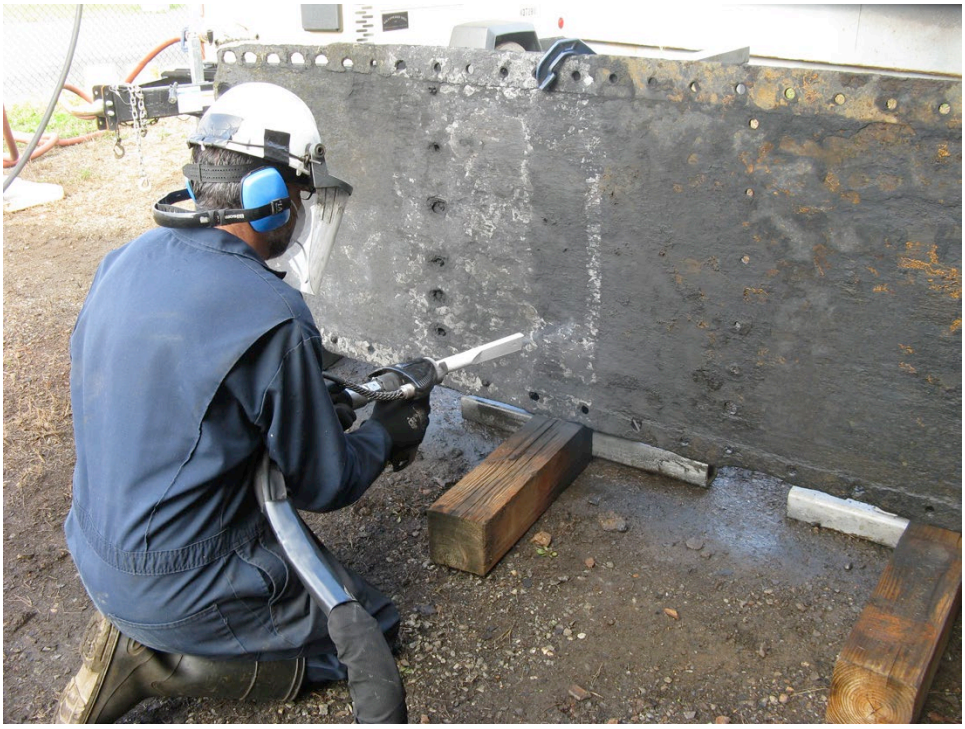


Figure 6. Mariners' staff member Michael Saul is treating an archaeological iron object while wearing all appropriate PPE, including cold protection gloves. Image courtesy of The Mariners' Museum and Park.

Cold Protection

Hands must be protected from extreme cold temperatures caused by dry ice. During the blasting process, components of the blasting unit, particularly the nozzle, can become cold and ice over due to contact with dry ice. Cold protection gloves should be worn whenever CO_2 is handled or DIB units are used to protect skin. (Fig. 6)

Depending on the size and requirements of your workspace, remember that bystanders or other staff in the lab may need PPE even if they are not working directly with the DIB treatment.

Conclusion

Dry ice blasting is a unique and effective method for the removal of dirt, corrosion, concretion, and aged coatings from a variety of museum objects. When used safely, it can both reduce treatment time and produce superior treatment results for the objects. While this report covered many topics concerning health and safety, this can only be considered a general overview. If your lab decides to try DIB treatment, please be sure to conduct further research that is specific to your lab's needs and requirements. Included below is a list of resources that can be used when creating a lab specific health and safety plan for dry ice blasting.

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Safety Resources:

United States Department of Labor. 1983. "OSHA Guidelines for Noise Enforcement; Appendix A"

OSHA Directive CPL 02-02-035. Access date: 8 June 2020. https://www.osha.gov/enforcement/directives/cpl-02-02-035

United States Department of Labor. 2002. "OSHA 3074 Hearing Conservation" Access date: 8 June 2020. https://www.osha.gov/Publications/OSHA3074/osha3074.html

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United States Department of Labor. "General Respiratory Protection Guidance for Employer and Workers" OSHA Bulletin. Access date: 8 June 2020. https://www.osha.gov/dts/shib/respiratory_protection_bulletin_2011.html

United States Department of Labor. "OSHA Technical Manual, Section III: Chapter 3, Ventilation Investigation" OSHA Technical Manual. Access date 8 June 2020. https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_3.html#3

United States Department of Labor. 2016 "OSHA 1910.133 Occupational Safety and Health Standards: Eye and face protection" Access date: 8 June 2020. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.133

United States Department of Labor. 2011. "OSHA 1910.146 Occupational Safety and Health Standards: Permit-required confined spaces" Access date: 8 June 2020. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.146

United States Department of Labor. "Safety and Health Guides: Cold Stress Guide" Access date: 8 June 2020. https://www.osha.gov/SLTC/emergencypreparedness/guides/cold.html

United States Department of Labor. 2008. "OSHA 1910.95 Occupational Health and Environmental Control: Occupational Noise exposure." Access date: 8 June 2020. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.95

United States Department of Labor. "Confined Spaces" Access date 8 June 2020. https://www.osha.gov/SLTC/confinedspaces/

Dry Ice Blasting Resources:

Brush, M. B., 2010. "Using Dry Ice for Spray-Paint Removal on Weathering Steel," Journal of Preservation Technologies (APT Bulletin), Vol. 41 (1), Practice Point 8.

Hoffman, William, Laurie King, 2019. "Equipment Identification and the Development of Dry-Ice Blasting Parameters for Cleaning Archaeological Wrought Iron, Copper Alloys, and Gray Cast Iron." In ICOM-CC Metal Conference 2019 Preprints. Neuchatel: Switzerland, 265-272.

Kinder, J., R. D. Blumer, F. Schad, 2007. "Cleaning of Old Corroded Surfaces of Cast Iron by Blasting with Dry-ice," Special Issue Acta Metallurgica Slovaca 13: 925- 931.

King, Laurie, William Hoffman. 2017. "Guns and Ships: Using Dry Ice Blasting in the Conservation of Cast Iron." Poster presented at the AIC 45th Annual Meeting, Chicago, May 2017.

Silverman, Randy H. 2008. "Fire and Ice: A Soot Removal Technique Using Dry Ice Blasting." Archival Product News, 15(3), 1-8. https://archival.com/newsletters/apnews-vol15no3.pdf

Spur, G., E. Uhlmann, F. Elbing. 1999. Dry-Ice Blasting for Cleaning: Process, Optimization and Application. Wear (1999) 233-235, 402-411.

Van der Molen, R., I. Joosten, T. Beentjes, L. Megens. 2011. Dry Ice Blasting for the Conservation Cleaning of Metals. In ICOM-CC Metal Conference 2010 Preprints. Charleston, South Carolina, October 2010, P. Mardikian: 96-103. Clemson: Clemson University.