Chapter 2.9.5
Carbon Dioxide (Dry-Ice) Blasting

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Basic Principles of Operation

Dry-ice particle blasting is similar to sand blasting, plastic bead blasting, or soda blasting where a media is accelerated in a pressurized air stream (or other inert gas) to impact the surface to be cleaned or prepared. With dry-ice blasting, the media that impacts the surface is solid carbon dioxide (CO_2) particles. One unique aspect of using dry-ice particles as a blast media is that the particles sublimate (vaporize) upon impact with the surface. The combined impact energy dissipation and extremely rapid heat transfer between the pellet and the surface cause instantaneous sublimation of the solid CO_2 into a gas. The gas expands to nearly eight hundred times the volume of the particle in a few milliseconds in what is effectively a "micro-explosion" at the point of impact that aids the coating removal process. Because of the CO_2 vaporizing, the dry-ice blasting process does not generate any secondary waste. All that remains to be collected is the removed coating.

As with other blast media, the kinetic energy associated with dry-ice blasting is a function of the particle mass density and impact velocity. Since CO_2 particles have a relatively low density, the process relies on high particle velocities to achieve the needed impact energy. The high particle velocities are the result of supersonic propellant or air-stream velocities. Unlike other blast media, the CO_2 particles have a very low temperature of –109°F (–78.5°C). This inherent low temperature gives the dry-ice blasting process unique thermodynamically induced surface mechanisms that affect the coating or contaminate in greater or lesser degrees, depending on coating type. Because of the temperature differential between the dry-ice particles and the surface being treated, a phenomenon known as fracking, or thermal shock, can occur. As a material's temperature decreases, it becomes embrittled, enabling the particle impact to break-up the coating and sever the chemical bond that is weakened by the lower temperature. The thermal gradient or differential between two dissimilar materials with different thermal expansion coefficients can serve to break the bond between the two materials. This thermal shock is most evident when blasting a nonmetallic coating or contaminate bonded to a metallic substrate.

Historical Development

In the early 1930s, the manufacture of solid phase carbon dioxide (CO_2) became possible. During this time, the creation of "dry ice" was nothing more than a laboratory experiment. As the procedure for making dry ice became readily available, applications for this innovative substance grew. Obviously, the first use was in refrigeration. Today, dry ice is widely used in the food industry for packaging and protecting perishable foods.

In 1945, the U.S. Navy experimented with dry ice as a blast media for various degreasing applications. In May 1963, Reginald Lindall received a patent for a "method of removing meat from bone" using "jetted" carbon dioxide particles.

In November 1972, Edwin Rice received a patent for a "method for the removal of unwanted portions of an article by spraying with high velocity dry ice particles." Similarly, in August 1977, Calvin Fong received a patent on "sandblasting with pellets of material capable of sublimation."

The work and success of these early pioneers led to the formation of several companies in the early 1980s that pursued the development of dry-ice blasting technology.

Dry-ice pelletizers and blast machines entered the industrial markets in the late 1980s. At that time, the blast machines were integrated with dry-ice production machines and therefore physically large and expensive, and they required high air pressure (greater than 200 psi [1.4 MPa]) for operation.

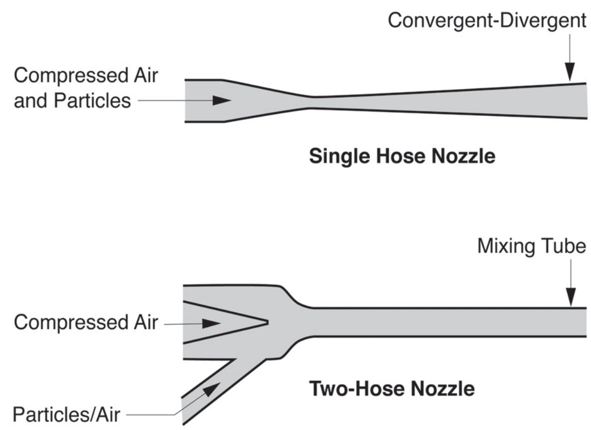
As the CO_2 blast technology advanced, the blast machines were separated from the production of dry ice and the size and cost dropped. Improved nozzle technology and production of high-density dry ice pellets has made blasting effective at shop air pressures (80 psi [550kPa]).

Figure 1. Dry ice blasting machine. Courtesy Cold Jet Inc.

Equipment/Materials

There are two general classes of blast machines as characterized by the method of transporting pellets to the nozzle: two-hose (suction design) and single-hose (pressure design) systems. In either system, proper selection of blast hose is important because of the low temperatures involved and the need to preserve particle integrity as the particles travel through the hose.

In the two-hose system, dry-ice particles are delivered and metered by various mechanical means to the inlet end of a hose and are drawn through the hose to the nozzle by means of vacuum produced by an ejector-type nozzle. Inside the nozzle, a stream of compressed air (supplied by the second hose) is sent through a primary nozzle and expands as a high-velocity jet confined inside a mixing tube. When flow areas are properly sized, this type of nozzle produces vacuum on the cavity around the primary jet and can therefore draw particles up through the ice hose and into the mixing tube where they are accelerated as the jet mixes with the entrained air/particle mixture. The exhaust Mach number from this type of nozzle is, in general, slightly supersonic. Advantages of this type of system are relative simplicity and lower material cost, along with an overall compact feeder system. One primary disadvantage is that the associated nozzle technology is generally not adaptable to a wide range of conditions (i.e., tight turns in a cavity, thin-wide blast swaths, etc.). Also, the aggression level and strip rate of the two-hose system is less than comparable single-hose blast machines.



CO_2 particle blast nozzle types are depicted above.

Figure 2. Single- and two-hose systems. Courtesy Cold Jet Inc.

In a single-hose system, particles are fed into the compressed air line by one of several types of airlock mechanisms. Reciprocating and rotary airlocks are both currently used in the industry. The stream of pellets and compressed air is then fed directly into a single hose followed by a nozzle where both air and pellets accelerate to high velocities. The exhaust Mach number from this type of nozzle is generally in the 1.0–3.0 range, depending on design and blast pressure. Advantages of this type of system are wide nozzle adaptability and the highest available blast aggression levels. Disadvantages include relatively higher material cost due to the complex airlock mechanism.

Blast machines are also differentiated into dry-ice block shaver blasters and dry-ice pellet blasters. The block shaver machines take standard 60 lb (27 kg) dry-ice blocks and use rotating blades to shave a thin layer of ice off. This thin sheet of dry ice shatters under its own weight into sugar grain-sized particles that fall into a funnel for collection. A two-hose delivery system is used to transfer the particles at the bottom of the funnel to the surface to be cleaned. The low mass of these particles combined with the inefficient two-hose system limits the block shavers to light-duty cleaning. Because the shaved ice machines deliver a particle blast with high flux density (number of particles striking a square area of surface per second), they are effective on thin, moderately hard coatings such as an air-dried, oil-based paint. The disadvantage of the ice shaver is the particle size and flux density is fixed as well as the particle velocity.

In contrast, pellet blast machines have a hopper that is filled with pre-manufactured CO_2 pellets. The hopper uses mechanical agitation to move the pellets to the bottom of the hopper and into the feeder system. The pellets are extruded through a die plate under great pressure. This creates an extremely dense pellet for maximum impact energy. The pellets are available in several sizes ranging from 0.040 inch (1 mm) to 0.120 inch (3 mm) in diameter. The 0.120 inch (3 mm) in diameter pellets are commercially available and are shipped as freight or delivered by the vendor's trucks. With a single-hose delivery system, the blast hose diameter and interior wall roughness and nozzle used govern the final pellet size and blast flux density exiting the nozzle. Because of its design, the single-hose pellet blast units are capable of "dialing-in" the correct blast type needed for a wide range of individual coatings or contaminates.

The equipment and materials needed for operation, aside from the blasting machine and accessories, are the supplies of dry ice, compressed air, and often single-phase 115 VAC electricity.

The dry-ice supply may be either pre-manufactured pellets or block, or pellets manufactured at the point of use. The pre-manufactured dry-ice pellets or block are stored and shipped in special insulated containers. These containers are typically large, double-wall construction molded polyethylene boxes with urethane foam insulation between the inner and outer walls. They are fitted with special gaskets and vapor barriers to maintain a very tight seal on the tote box lid after the pellets have been produced. The boxes typically contain from 400 to 1200 lb (180 to 540 kg) of product and are equipped with fork-lift channels. While quality, as measured by particle density and water content, may vary, dry ice is essentially a commodity and variations in price by geography are fairly significant.

The compressed air requirements will vary somewhat depending on the application and the particular blast machine and nozzle. For most applications with moderate difficulty or located within a manufacturing plant, requirements are approximately 80 to 100 psi (550 to 690 kPa) at 200 CFM (5.7 m^3/min). Removal of paint and other well-bonded coatings will usually require higher pressures and flow rates that fall between those and 300 psi (21 MPa) at 350 CFM (9.9 m^3/min).

Major Markets for Dry-Ice Blasting

Molded Products

Dry-ice blasting cleans unwanted release agents ("parting agent") and/or residual material build up from the product contact surfaces. That is, the build-up of release agents or residual product from the hot mold is easily removed. Dry-ice blasting allows the tools or molds to be cleaned while the mold is hot and still in the press. This reduces the "press down time due to cleaning" by 80 to 95%. Since the process is non-abrasive, the CO_2 blast cleaning will not wear the tools or open critical tool tolerances. Furthermore, "micro vents" are typically cleaned by dry-ice blasting. This eliminates hand drilling of plugged vents needed for optimum gas escape. Types of molds cleaned by CO_2 blasting include:

- Rubber molds, mixers, and other process equipment
- Tire molds
- Automotive interior and other urethane molds
- Molds for bottles and other blow molded products
- Core boxes and permanent foundry molds.

Food Industry

Residual sugars left behind from baking can be readily removed from their fixtures in most cases. Here, as in molding, heat may enhance removal speed and characteristics. In many cases, the application may be performed on-line.

A key benefit in using dry-ice blasting to replace some of the general cleaning done with water, detergents, and sanitizers is a moisture reduction, thereby, inhibiting the growth of bacteria—particularly salmonella. Economics have directed on-line cleaning of fixtures including waffle irons and other similar batter or dough baking and product-forming fixtures, oven bands, and conveyor belts.

CO_2 blasting has been proven to remove and/or destroy significant biofilm build-ups of listeria and salmonella. Typical applications are performed without shutting down or disassembly and include:

- Wafer plates—carbon build-up removal
- Cookie oven bands, baking ovens, shelves, and trays
- Flight and conveyor cleaning
- Ingredient build-up from tanks and vessels.

Miscellaneous Tooling

There are many names and types of production fixtures, but virtually any item that is part of the production process and is difficult to clean on-line or during production hours by traditional means may be an excellent dry ice application, such as:

- Conveyor components and other materials handling equipment
- Weld slag removal from robotics, fixtures, carriers
- Removal of oils and grease from chains, machinery, etc.
- Cleaning packaging equipment
- Removal of adhesives

Printing Industry

In the printing industry, inks and varnish polymers are designed to adhere to most surfaces, resist scratches, and, in some instances, be solvent resistant. These characteristics, which make their use attractive, also make the removal of dried ink very difficult. Ink buildup on the gears and deck guides causes poor alignment and results in low print quality. To compensate for these phenomena, plate mounting generally needs adjusting several times to register critical graphics in order to produce an acceptable quality level. Generally, each "press run" to check the register of the colors results in thousands of feet of wasted material. This inherently wasteful process may be eliminated by the on-line precision cleaning ability of dry-ice blasting.

Applications for Dry-Ice Blasting

In simple terms, dry-ice blasting is not a paint stripper. While isolated success cases exist in paint stripping using blast pressures from 150 to 300 psi (1 to 2 MPa), most results indicate partial to complete failure to remove topcoats at profitable rates, and failure is even more likely when the goal is to completely remove a primer. Successful applications in painting-related projects are the rule rather than the exception when:

- Dry-ice blasting is employed to prepare a surface for painting without the need to completely remove a coating
- The work surfaces are near sensitive machinery or other circumstances where airborne grit or water would be detrimental
- Over-spray accumulates in thick layered deposits such as paint booths. (Thick coatings respond to the thermal effects better than thin coatings.)

Hazardous Coatings and Materials

Due to media vaporization, removed materials such as lead paint, asbestos, or coatings that are radioactive or contaminated with PCBs need no further separation before processing for disposal, nor is the volume increased as a result of being mixed with water, grit, chemicals, or other cleaning agents.

Greasy Factory Ceilings

Dry-ice blasting is effective on greases and oils and is now being used to prepare greasy factory ceilings for repainting. The effluent from the operation is negligible so that the need to cover sensitive machinery is minimal. After blasting with dry ice, the surface is ready for coating and no rinsing or other operation is needed.

Flaking Factory Ceilings

While dry-ice blasting is not effective at stripping well-bonded coatings, it is very effective at removing a coating that is flaking or not well bonded.

On areas of the ceiling that have good paint adhesion, preparation involves just cleaning those areas so they are ready for coating. The machinery on the shop floor can be loosely covered.

Repainting Machines, Machine Tools, and Equipment

Complete machines can be cleaned without removing the factory paint and made ready for repainting with little or no other preparation such as masking or rinsing.

Dry-ice blasting is much faster and more thorough than manual preparation, has no airborne grit to ruin bearings and other moving parts, and does not "short-out" motors and electrical controls like water blasting does.

New Construction Structural Steel Paint Preparation

Red iron joists that become muddy during storage are cleaned just prior to installation. By avoiding the alternative of using pressure washing, not only is there less mess, but also the surface is free of flash rust and ready for installation and topcoat if desired.

Concrete Floor Preparation for Paint (Oil Removal)

Whether using sand blast, shot blast, or acid to roughen the surface for painting, those areas that have oil embedded in the concrete will not bond to the coating to be applied.

Dry-ice blasting is being used on the oil and grease stained areas with great success compared to chemical or citrus-based degreasers. The oil that often has leached deep into the concrete is drawn out and blasted away so that the area can be coated with uniform appearance and bonding.

Wrought Iron at Historical Sites

Wrought iron (circa 1930) is being restored using dry-ice blasting as the paint preparation in a botanical garden setting. Not only is grit blasting detrimental at this location due to the plant life and some of the historic structures, but also the iron itself is thin in many areas due to years of corrosion. Dry-ice blasting has just enough abrasive to remove the flaking rust and loose paint without eroding too much of the deteriorating iron as stronger abrasives can. It is also much faster and more thorough than manual methods and better at getting into hard to reach portions of the iron.

FLASHJET®

This patented coatings removal process uses pulsed-Xenon light combined with a dry-ice blast stream to strip all types of coatings from both composite and metallic substrates without damage. Both the Department of Defense and the Federal Aviation Association have approved the system for aircraft.

Advantages of CO_2 Blasting

Cost Reduction. The natural sublimation of dry-ice particles eliminates the cost of collecting the cleaning media for disposal. In addition, containment and collection costs associated with water/grit blasting procedures are also eliminated.

Improved Productivity. Because CO_2 blast systems provide on-line maintenance capabilities for production equipment, timely and expensive detooling procedures are kept to a minimum. Dedicated cleaning cycles are no longer required as preventative maintenance schedules can be adopted that allow for equipment cleaning during production periods. As a result, throughput is increased without adding labor or production equipment.

Extension of Equipment's Useful Life. Unlike sand, walnut shells, plastic beads, and other abrasive grit media, dry-ice particles are non-abrasive. Cleaning with dry ice will not wear tooling, texture surfaces, open tolerances, or damage bearings or machinery. Blast nozzles and hoses do not wear and need to be replaced. In addition, on-line cleaning eliminates the danger of molds being damaged during handling.

A Dry Process. Unlike steam or water blasting, CO_2 blast systems will not damage electrical wiring, controls, or switches. Also, any possible rust formation after cleaning is far less when compared to steam or water blasting. When used in the food industry, dry-ice blasting reduces the potential for bacteria growth inherent to conventional water blasting.

Limitations Compared to Abrasive Blast. Because of the lack of hardness inherent in the media, coatings removal rates are significantly less than that for dry or wet abrasive blasting and due to the lack of particle hardness, no surface profile or anchor patterns result from dry-ice blasting metal surfaces.

Environmental/Safety Advantages and Concerns for CO_2 Blasting

Environmental Safety. Carbon dioxide is a non-toxic element that meets EPA, FDA, and USDA industry guidelines. By replacing toxic chemical processes with CO_2 blast systems, employee exposure and corporate liability stemming from the use of dangerous chemical cleaning agents can be materially reduced or eliminated completely. The vaporization of the media is an environmental advantage since most surface preparation methods exhibit a dust or fume attributable to the media used.

Since CO_2 gas is heavier than air (CO_2 gas displaces oxygen) care must be taken if blasting in enclosed areas or down in a pit. As dry ice is very cold, insultated gloves should be worn as a precaution. Other personal protective equipment includes face shields, hearing protection, and long-sleeve clothing. Noise levels are high, but within OSHA guidelines when the operators use properly fitted hearing protection.

The effects of accidental personal contact with the blast stream are certainly not pleasant but are not life threatening, being limited to skin surface lesions or welts rather than breaking skin. As with most blasting, electrostatic discharge can occur when the target is not well grounded. In theory, the concentration of carbon dioxide minimizes the danger of explosion. The carbon dioxide used is food grade and is obtained as a byproduct of other industrial processes and therefore does not contribute to "the greenhouse effect."

Waste Containment and Disposal. Waste containment and disposal is limited to the substance being removed, since dry ice completely vaporizes. Containment or covering of adjacent items may be necessary if the material being removed is either wet or viscous, or becomes small airborne particles when blasted. Studies have shown that the average particle size of removed coatings is larger than that of abrasive blasting particles so that dust containment is much less challenging when blasting particle vaporization is considered.[1]

Weather Restrictions

Dry-ice blasting may be employed in most weather circumstances. Rain poses the challenge of keeping the media dry before it is in the machines hopper. Extreme heat and high humidity are challenging since the media is a desiccant and absorbs moisture that causes clumping and can interrupt the blast flow.

Cleaning Rate and Cost Information

Acquisition, rental costs, and cleaning service vary by manufacturer or contractor.

Operating Costs

The major operating cost is the dry-ice media. Most users purchase dry ice as needed and either have it delivered or use their truck and driver. While supply and demand does cause considerable geographical pricing variations, 25 cents per pound ($0.55/kg) with a usage of 3 pounds per minute (6.6 kg/min) are good budgetary averages. Therefore, hard operating costs are $45 per hour of continuous blasting.

Maintenance and depreciation are less than for most equipment in this category because the non-abrasive media does not cause wear on the flow-path components.

Paint Removal

If a coating is removed at the rate of 0.25–0.33 ft^2/min (0.023–0.031 m^2/min), this is the best that can be expected on a relatively new, properly applied finish. When the removal rate is low it will decrease over time as the substrate becomes extremely cold and the thermal effects diminish. Sometimes it may take one minute just to break through the coating film with the nozzle remaining stationary over a single point. Primers often respond this way.

On a coating that is weathered or was applied improperly, results can be significantly better, up to 1 ft^2/min (0.09 m^3/min) or more. In some cases, it may be advantageous to use chemical agents to pre-treat (soak) the surface, with some of the agents citrus-based.

Surface Preparation

When the objective is to remove dirt, grease, oil, and loose paint so the surface can be repainted, rates will most often be in the range of 3–6 ft^2/min (0.28–0.56 m^2/min). After treatment, the surface is ready to paint and no final rinse or any other preparation is needed.

Nonvisible Contamination

When dry-ice blasting is applied to a surface, no residue from the blasting agent remains and therefore, notwithstanding any oil or other contamination from the compressed air that could remain, the surface is free from any visible or non-visible contamination.

Compatibility with Paint Types

Dry-ice blasting is compatible with all types of paint in that there is no danger of a secondary compound being formed. It may not be able to remove all types of paint with significant removal rates, but it can create a clean, rinse free, and water-break free surface ready to be coated.

Expected Advances in Dry-Ice Blast Technology

Systems are expected to become more efficient in terms of media and air consumption as well as smaller, lighter, and less expensive to purchase and to operate. Similarly, operator comfort and convenience should improve as well with progress on noise reduction and ergonomics heading the list. The expected trend is for the supply of dry-ice media to increase while cost-effectiveness improves.

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