

The Fundamentals of Dry Ice Blast Cleaning

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Today, CO₂ blasting is being effectively used in a wide array of applications from heavy slag removal to delicate semiconductor and circuit board cleaning. Imagine a process that can be used on-line without damaging equipment or requiring a machine "teardown". Unlike conventional toxic chemicals, high pressure water blasting and abrasive grit blasting, CO₂ blasting uses dry ice particles in a high velocity air flow to remove contaminants from surfaces without the added costs and inconvenience of secondary waste treatment and disposal.

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Introduction

In the early 1930's, the manufacture of solid phase carbon dioxide (CO₂) 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, stories exist of the U.S. Navy experimenting 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 1980's that pursued the development of Dry Ice Blasting Technology. In 1986, Cold Jet, Inc. was founded in the State of Ohio by Mr. Newell Crane.

Dry Ice pelletizers and blast machines entered the industrial markets in the late 1980's. At this time the blast machines were physically large, expensive, and required high air pressure for operation (pressures greater than 200 PSI). As the CO₂ blast technology advanced, the blast machine's size and cost dropped. The latest nozzle technology has made blasting effective at shop air pressures (80 PSI).

What Is Dry Ice?

Dry Ice is the solid form of Carbon Dioxide (CO₂), which is a colorless, tasteless, odorless gas found naturally in our atmosphere. Though it is present in relatively small quantities (about 0.03% by volume), it is one of the most important gases we know of.

CO₂ is a natural media which serves many life sustaining purposes. It is a key element involved in the carbon cycle; it is the only source of carbon for the carbohydrates produced by agriculture; it stimulates plant growth; and it helps to moderate the temperature of the earth overall. Animal respiration is believed to add 28 million tons of Carbon Dioxide per day into the atmosphere. By contrast, the U.S. CO₂ industry can supply only 25,000 tons per day and 95% of this amount is from by-product sources, or less than 0.04% of the other sources combined.

With a low temperature of -109° F, Dry Ice solid has an inherent thermal energy ready to be tapped. At atmospheric pressure, solid CO₂ sublimates directly to vapor without a liquid phase. This unique property means that the blast media simply disappears, leaving only the original contaminant to be disposed of. In addition, cleaning in water sensitive areas is now practical.

The grade of carbon dioxide used in blasting is the same as that used in the food and beverage industry and has been specifically approved by the FDA, the EPA and the USDA. Carbon dioxide is a non-poisonous, liquefied gas which is both inexpensive and easily stored at work sites. Of equal importance, it is non-conductive and non-flammable.

CO₂ is a natural by-product of several industrial manufacturing processes such as fermentation and petrol-chemical refining. The CO₂ given off by the above production processes is captured and stored without losses until needed. When

the CO₂ is returned to the atmosphere during the blasting process, no new CO₂ is produced. Instead, only the original CO₂ by-product is released.

Listed in **Table 1** are the physical properties and conversion factors for CO₂ in its various forms:

Table 1. Carbon Dioxide (CO₂) properties.

Molecular Weight	44.01
Density (Solid)	97.5 LB/ft ³ at -109° F
Density (Liquid)	63.7 LB/ft ³ at 0° F
Density (Gas)	0.123 LB/ft ³ at 32° F
Melting Point	-69.9° F at 75.1 psia (triple point)
Boiling Point	-109.3° F (sublimates)
Liquid-to-Gas Conversion Rate	8.726 SCF (gas)/LB (liquid at 0°F and 305 psia)
Liquid-to-Snow Conversion Rate	.46 LB snow / LB liquid at 0.0° F
	.57 LB snow / LB liquid at -55.0° F

Media Manufacture

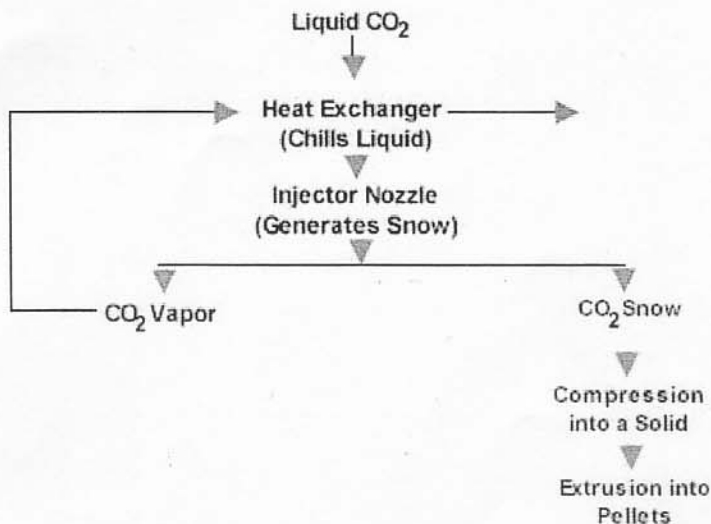
In Dry Ice blasting, there are several methods used to manufacture the Dry Ice blasting media. One technique is to shave dry ice granules from solid Dry Ice block at the blasting machine. This generally produces sugar-crystal sized Dry Ice granules, which must be used quickly due to fast sublimation (due to their high surface area-to-volume ratio).

Another technique is to manufacture hard pellets of Dry Ice in a pelletizer then immediately blast with the pellets or store the pellets in an insulated container until the pellets are required. These pellets are generally on the order of 0.080" to 0.120" in diameter, and 0.100" to 0.400" in length.

In this method, Dry Ice is manufactured by flashing pressurized liquid CO₂ into snow, followed by compression of the snow into solid form. The snow is either directly nuggetized into pellets (mechanical compression) or is extruded into solid pellet form through a die under hydraulic pressure. The latter process allows for more efficient conversion from the liquid phase to the solid phase. Generally, it is desirable to have pellets which are well compacted, to minimize entrapment of gaseous CO₂ and/or air which may affect product quality.

As can be seen in Table 1, the yield achieved when flashing liquid carbon dioxide into snow increases as the temperature of the liquid CO₂ decreases, so it is important to pre-chill the incoming liquid CO₂ via heat exchangers with the outgoing CO₂ vapor. Figure 1 is a block diagram showing a basic pelletization process.

Figure 1. Pelletization Process.



Several manufacturers make Dry Ice pelletizers which may prove beneficial to have on-site for customers with high pellet demand. Facilities required for such an arrangement are generally as follows: a refrigerated liquid CO₂ tank, a pelletizer, and liquid CO₂ lines to reach the equipment. Some manufacturers make combined Dry Ice pelletizer/blast machines which manufacture Dry Ice and blast all in one operation. Facilities required for such an arrangement are: An air compressor (typically either 120 PSIG at 250 SCFM or 350 PSIG at 250 SCFM), a liquid CO₂ tank, a pelletizer/blast machine, compressed air hose and liquid CO₂ lines to reach the equipment, blast hose from the machine to the blasting operation, and the appropriate nozzle(s) for the application. This equipment is best suited to high volume, continuous blasting applications where the cost savings of manufacturing pellets on-site justifies the capital expenditure for the system.

How Does Dry Ice Blasting Work?

The Basic Process

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 (CO₂) particles. One unique aspect of using Dry Ice particles as a blast media is that the particles sublime (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 CO₂ into gas. The gas expands to nearly eight hundred times the volume of the pellet in a few milliseconds in what is effectively a "micro-explosion" at the point of impact. Because of the CO₂ vaporizing, the Dry Ice blasting process does not generate any secondary waste. All that remains to be collected is the contaminate being removed.

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 CO₂ particles have a relatively low hardness, the process relies on high particle velocities to achieve the needed impact energy. The high particle velocities are the result of supersonic propellant or airstream velocities.

Unlike other blast media, the CO₂ particles have a very low temperature of -109° F. 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. Refer to Figures 2 and 3.

FIGURE 2. Thermal shock induces micro-cracking in the surface coating

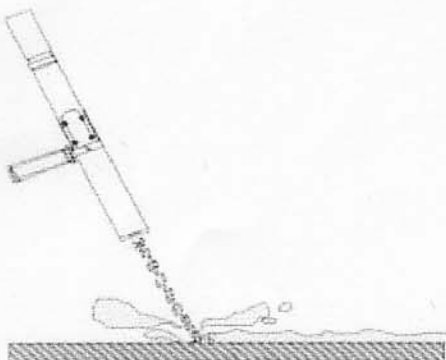


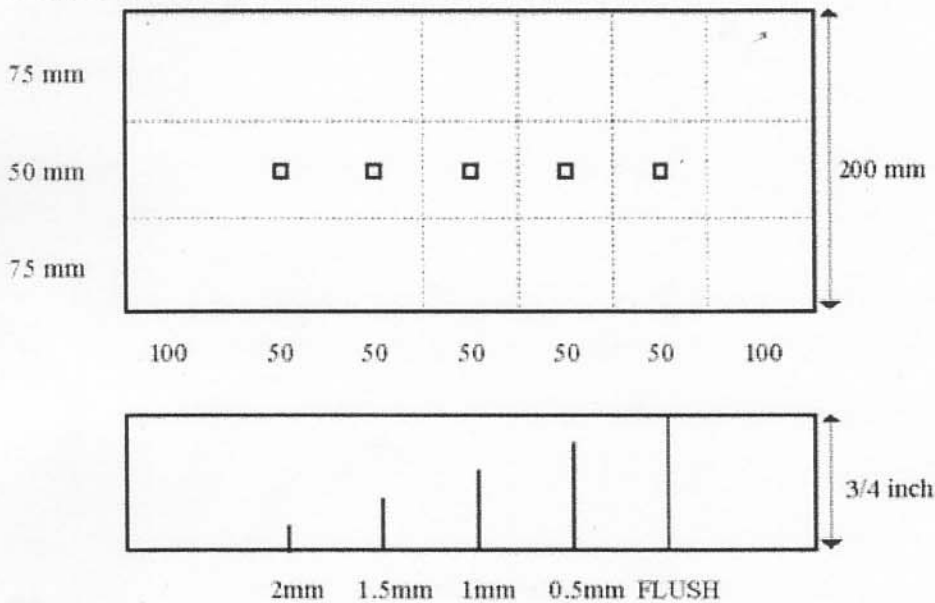
FIGURE 3. CO₂ gas expansion and pellet kinetic effects break away and remove coating particles.



Also, 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 non-metallic coating or contaminate bonded to a metallic substrate.

Quite often companies examining this process are concerned with the effect the thermal shock will have on the parent metal. Studies have shown that the temperature decrease occurs on the surface only, there is no chance of thermal stress occurring in the substrate metal. To illustrate this principle, an experiment was performed where thermocouples were imbedded into a steel substrate at varying depths (flush with the surface to 2 mm deep). Refer to Figure 4.

FIGURE 4. Thermocouple Distance From Plate Surface.



A CO₂ blast jet was constantly traversed across the test specimen for 30 seconds (a relatively long dwell time for this process) and the thermal couples recorded the changing temperatures at the various depths. As shown in Figure 5, the surface mounted thermocouple shows a temperature drop each time the blast jet impinged directly upon the thermocouple (50° C in about 5 seconds). In contrast, the thermocouples imbedded at various depths in the substrate recorded a slow gradual drop in temperature corresponding to the overall test plate temperature drop. The thermocouple 2mm deep only dropped 10° C after 30 seconds. This curve illustrates that the "Thermal Shock" occurs only at the surface where the coating or contaminate is bonded to the substrate (Reference 1) and has no detrimental effect to the substrate.