by Marcela R. Stacey and Dennis N. Bingham

Cryogenic Cutting and Cleaning

Many industrial tasks call for cutting or cleaning some kind of material. These jobs can be done with waterjetting—using a high-pressure jet of water to cut materials or to remove coatings including paint and rust. However, leftover water may become contaminated with whatever material is being cut or removed. After the job, this so-called secondary waste—a volume of particulate-containing water—requires treatment and disposal. To help avoid secondary waste, investigators at the Idaho National Engineering Laboratory (INEL) in Idaho Falls developed cryogenic processing, a method that uses high-velocity jets of liquefied and solidified atmospheric gases for cutting and cleaning.

During the earliest developmental stages of this technique, INEL engineers asked, "Why not use a jet of liquid nitrogen in place of water?" This alternative offers several significant benefits. First, liquid nitrogen does not create secondary waste because upon release it returns to its gaseous state and escapes into the atmosphere, which already consists of 78% nitrogen by volume. Second, it is relatively inexpensive. Third, nitrogen is basically inert at ambient conditions, posing no hazard of explosion, fire, or oxidation (reaction). Finally, it can be used in a much wider range of applications than noninert gases such as oxygen.

Parts in the process

The current cryogenic system consists of four major subsystems: fluid supply, pressurization, nozzle, and process control (Figure 1). The supply subsystem consists primarily of a 23-m^3 storage tank. The pressurization subsystem is a combination of pumps, intensifiers, and heat exchangers that pressurize and cool the nitrogen in several stages until it reaches approximately 416 megaPascal (MPa) and –142° C. The cryogenic jet is routed to the nozzle subsystem, which may consist of a standard waterjet orifice. The process-control subsystem allows the operator to adjust various jet parameters.

There is a correlation between the nozzle's configuration and the jet's effectiveness. So far, the 0.2-mm and 0.25-mm HiCoh (high coherence) waterjet orifices, made by A. T. Gatti, Inc. (Trenton, NJ), appear to work much better than other conventional waterjet nozzle inserts. The Gatti inserts produce a tight jet over a much longer distance before the jet begins to feather and disintegrate. The nitrogen jet leaves the nozzle at velocities greater than 1,000 m/sec and at a mass flow rate of 19–63 cm^3/sec.

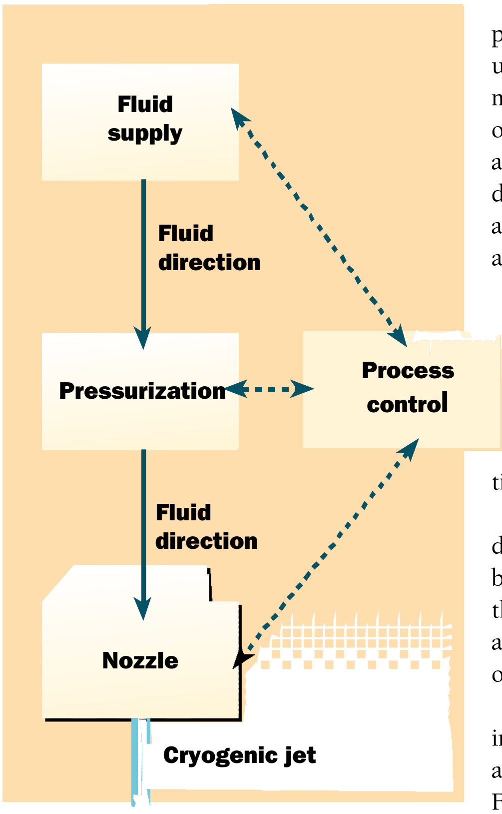

Figure 1. Schematic view of a cryogenic system for cutting and cleaning.

The cryogenic jet can be a single or multi-element gas that flows in one or more physical phases: gas, solid, or liquid. In addition, abrasives can be introduced to the jet at a specialized mixing zone. Potential abrasives include solid carbon dioxide, sand, diamond dust, aluminum-oxide grit, graphite, and others.

The most commonly used abrasive during this research was solid carbon dioxide particles, yet other abrasives can be selected as the application requires. For example, if generating a secondary waste stream is particularly undesirable, carbon dioxide particles may be the best abrasive. However, if process speed must be enhanced, a harsher abrasive can be selected to reduce processing time.

To produce different effects on a work piece, the process-control subsystem can be used to select different combinations of elements, phases, and abrasives. In addition, an operator can control other jet parameters: jet and abrasive temperature, pressure, standoff distance (the distance the jet travels in free air before it touches the work piece), impact angle, direction, and speed.

Tested materials

After successfully producing a cryogenic jet, the research focused on its effects on various materials. This jet works particularly well for two general processes: cutting/drilling and cleaning/abrading.

The first materials tested for cutting and drilling were paper, insulation, food, cardboard, plastics, and metals. As examples of the jet's cutting effectiveness during the first attempts, it cut through a 0.6-cm-thick layer of paper and a 0.6-cm-thick piece of lexan.

The first coating materials tested for cleaning and abrading were paint, surface debris, and radiological-contamination simulants. For example, X-ray fluorescence showed that the jet was particularly successful at removing SIMCON II—a simulated contaminant composed of known amounts of cesium and zirconium nitrate salts baked for 24 hours at 700° C on pieces of 304 stainless steel. That process produces a tough and tenacious oxide coat, which simulates many of the characteristics of radioisotopes such as surface adhesion and depth of penetration. The cryogenic jet also removed 0.203 mm of latex, epoxy, Teflon, and military paints from various base materials at rates greater than 0.23 m^2/min.

The success of the cryogenic process continues. In addition to the initial success, the cryogenic system has cut a wide variety of other materials including ceramic tile, 5,000-lb/in^2 concrete, propellants, explosives, stainless steel, carbon steel, aluminum, upholstery fabric, carbon composites, and many others. The system also abraded a variety of materials such as surface debris, rust, galvanized and heavy metal coatings, heavy-duty polyurethane, and others.

Although the cryogenic process was tested on so many materials, parametric data were collected for only a few. Three materials for which data were collected are carbon steel and stainless steel shim stock, standard waste drum steel, and aluminum. Example data are shown in Figure 2, which represents the relations among jet displacement speed, depth of cut, and mass removed.

Appropriate applications

Despite the advantages of cryogenic processing, it is not the best choice for all applications. Expected results—including schedule and budget constraints, amount and type of secondary waste, hazard control, public perception, and so on—must be considered and arranged in order of priority. Then, the jet parameters (working fluid, physical state, standoff distance, abrasive, etc.) can be selected to meet the requirements.

In some applications, a secondary waste stream may be inconsequential. Engineers may handle such cases with conventional methods: sandblasting, waterjetting, diamond cutting, or another cutting/abrading method. In other words, a cost-benefit analysis must be performed to match the jet parameters with the desired results.

Nevertheless, many industries face problems that could be solved with cryogenic processing. These areas include applications that require removal of paint, coatings, rust, and other types of surface debris from aircraft, ships, nuclear hardware, and other places where cutting or decontamination presents economic, logistic, or environmental challenges.

Cryogenic processing could be used in many specific applications:

- Removing barnacles from a ship's hull either in dry dock or in waterborne conditions.
- Removing scale in heat exchangers and boilers.
- Cleaning conduits and tanks, especially those containing flammable chemicals.
- Decreasing growth and spread of bacteria in the food-preparation industry.
- Remotely opening containers of nuclear materials or other hazardous waste without a heat source or secondary waste stream.
- Cleaning metallic surfaces and contaminated concrete surfaces and structures.

One particular benefit of cryogenic processing is in surface preparation, especially when surfaces must be kept clean and dry during processing. After cryogenic processing, a surface is immediately ready for subsequent processes, before oxidation can cause problems. For instance, the carbon steel industry requires dry processing to slow reactions, especially rusting. Carbon steel surfaces processed at the INEL have not rusted for approximately three years.

Cryogenic processing can also reduce preparation time. To cut effectively, a conventional cutting torch needs a working surface that is clear of coatings such as tile, paint, rust, or other build-up. Conversely, cryogenic jets can penetrate such coatings to cut the steel structures without the generation of a secondary waste stream. Cryogenic cutting also eliminates the need for a so-called fire watch. When cutting metal with a conventional cutting torch, a fire watch is needed to prevent the torch from igniting materials on the other side of the metal being cut. Cryogenic cutting eliminates the need for a fire watch on the exit side of the cut and the risk of inadvertent ignition.

The precise cost of using cryogenic processing depends on the application. Excluding labor, however, the current operating costs for cryogenic processing are estimated at $50–150 per hour. Keep in mind that this process can provide a cleaning effectiveness of 90% or better at a rate greater than 0.5 m^2 per hour—depending on the material and geometry of the work piece.

In general, industries that can greatly benefit from cryogenic processing are those that require cutting or cleaning of surfaces where economic, logistic, or environmental problems arise because of a secondary waste stream or from processing with high-temperature or "wet" methods.

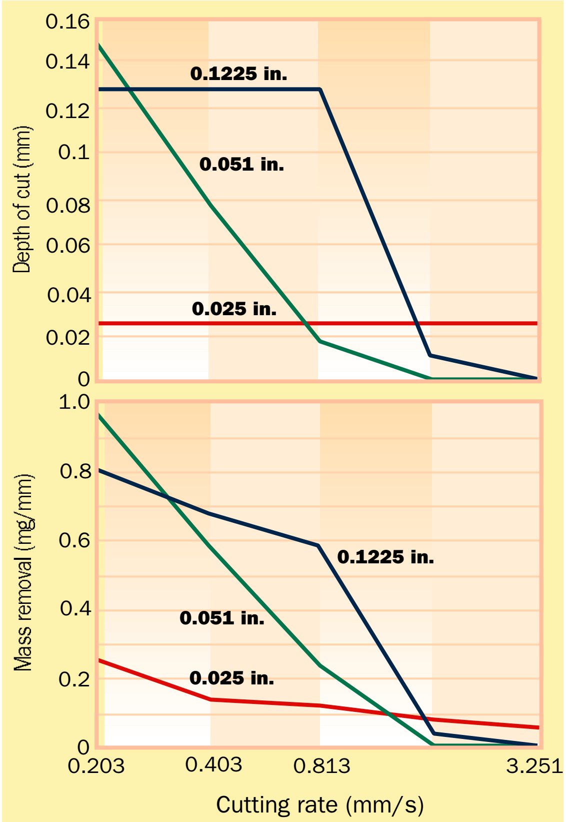

Figure 2. Cutting data for carbon steel of Brinell hardness 187 for three sample thicknesses.

Technology transfer

Transfer of cryogenic-processing technology from the U.S. Department of Energy (DOE) laboratories to the commercial sector was initiated through a Cooperative Research and Development Award (CRADA) with Cimetrix, Inc. (Provo, UT), and a licensing relationship was established with CryCle Cryogenics B.V. (Haarlem, The Netherlands). A test configuration ready for precommercial production is under construction by CryCle Cryogenics and will be marketed as a service system in selected recycling industries in Europe. This work was performed under contract with the DOE, Idaho Operations Office, Contract DE-AC07-76ID01570.

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