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A Centrifuge CO_2 Pellet Cleaning System*

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ABSTRACT

Centrifuge-based cryogenic pellet accelerator technology, originally developed at Oak Ridge National Laboratory (ORNL) for the purpose of refueling fusion reactors with high-speed pellets of frozen deuterium/tritium, is now being developed as a method of cleaning without the use of conventional solvents. In these applications large quantities of pellets made of frozen CO_2 or argon are accelerated in a high-speed rotor. The accelerated pellet stream is used to clean or etch surfaces. The advantage of this system is that the spent pellets and debris resulting from the cleaning process can be filtered leaving only the debris for disposal. This paper discusses the centrifuge CO_2 pellet cleaning system, the physics model of the pellet impacting the surface, the centrifuge apparatus, and some initial cleaning and etching tests.

1. INTRODUCTION

The centrifuge CO_2 cleaning system is a method of cleaning surfaces. Use of CO_2 is environmentally sound because it is readily available as a by-product stream from many industrial processes. The cleaning action takes place when the high-speed pellet of frozen CO_2 impacts the surface and knocks loose any contamination. Depending on the speed of the pellets, the cleaning action can be adjusted from a low-impact pressure regime up to an aggressive impact during which relatively hard surfaces can be removed or etched. The cleaning applications of the centrifuge-based pellet accelerator are similar to those of commercially available CO_2 pellet cryoblasting systems that use compressed air to accelerate the pellets. The distinguishing feature of the centrifuge system is that it can achieve much higher pellet speeds at increased efficiency, which allows the centrifuge system to perform more aggressive cleaning and etching tasks. For example, removing epoxy-based paints from aircraft, a task that previously used large quantities of methylene chloride solvents, may be economically feasible with high-speed CO_2 pellets. Another application is the cleaning of surfaces contaminated with radioactive substances. In these applications the lack of a secondary contaminated waste stream is of great benefit.

2. THEORY OF OPERATION

The centrifuge accelerates cryogenic pellets with virtually no contact forces between the pellet and the accelerator. The acceleration process utilizes the commonly known property that frozen CO_2 (dry ice) "floats" on a self-generated gas bearing when placed on a smooth surface. Pellets injected into a high-speed rotating track are thus accelerated with negligible friction loss. Figure 1 shows the typical geometry of a track in a centrifuge wheel. Pellets exiting the wheel have a speed v_p determined by the peripheral speed of the wheel v_w and the exit angle q between the track and the tangent of the wheel

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$$v_p = 2v_w \cos(\theta/2). \qquad (1)$$

The track geometry for our present wheel has an exit peripheral angle of 45 degrees giving a pellet speed of 1.85 times the wheel tip velocity. Speeds of up to 1600 ft/s (500m/s) and acceleration efficiencies of 80% (65% overall efficiency) have been achieved. All pellets accelerated by the wheel have essentially the same velocity, which means that the entire stream can be delivered to the surface at the optimal velocity for the particular application. This is in contrast to compressed air systems which deliver pellets with a range of velocities.

The interaction of the high speed pellet with a surface can be modeled using the same physics as the impact of a high speed fluid droplet on a surface as shown in Fig. 2. In this case the impact pressure created on the surface is given by the "water hammer" equation. This equation relates the impact stress s to the pellet velocity v_p, pellet density ρ_1 and compressive sound speed U_1:

$$\sigma = \rho_1 U_1 v_p \qquad (2)$$

for impact with rigid surfaces and

$$\sigma = \rho_1 U_1 \rho_2 U_2/(\rho_1 U_1 + \rho_2 U_2)\ v_p \qquad (3)$$

for impact with semirigid surfaces where $\rho_1 U_2$ are density and sound speed of the target material. The compressive sound speed is one measure of the pellet's hardness. Even though dry ice is relatively soft, at high speeds the pressures developed during impact can be made larger than the yield strength of most materials. Depending on the surface being impacted, there is a characteristic threshold velocity above which erosion takes place. It is interesting to note that this physics model corresponds to any abrasive media that is significantly softer than the surface being impacted. Therefore, all of the soft abrasive and liquid impact cleaning technologies are basically the same; that is, one would expect to achieve comparable results with high-pressure water, CO_2, or plastic media abrasives for comparable surface impact pressures as given by Eqs. 2 and 3.

The differentiating features of the soft abrasive technologies depend on the speed and efficiency of the acceleration technology, the cost of the equipment, the cost of the abrasive material, and the cost of the recovery or cost of disposal of the abrasive material. The principle advantage of the centrifuge CO_2 system is that it can achieve pellet speeds high enough to perform aggressive etching. Furthermore, it is efficient and the waste processing is done with a simple high-efficiency air filtering system. Another distinguishing feature of the CO_2 system is that during impact the CO_2 is converted from a solid to a high-pressure, supercritical fluid that undergoes a rapid decompression and expansion that can be quite effective in dissolving hydrocarbons and in sweeping away surface deposits. These effects are especially important in cleaning porous surfaces.

3. EQUIPMENT

The hardware used to accelerate the CO_2 pellets consists of a high-speed electric motor and a specially designed aluminum accelerator disk. The tests done to date at ORNL have been performed on a modified research apparatus that was previously used to accelerate frozen hydrogen pellets for fusion experiments. This apparatus had limited horsepower capability and was in a chamber that restricted the size of samples being tested. Two new apparatuses are under construction which were designed specifically for cryoblasting tests.

The first unit, Fig. 3, will use a 30-HP high-speed induction motor to drive an 18-in (0.46-m) diameter wheel. The unit will be capable of pellet speeds of 1600 ft/s (500 m/s) and pellet throughputs of over 1,000 lb per hour. This system is combined with a special sample chamber installed inside a glovebox so that tests of radioactive materials can be performed. The apparatus is also equipped with the capability to produce pellets of solidified argon in addition to CO_2. Argon pellets are used for applications that require cleaning of materials that are chemically reactive with CO_2. Tests of the cleaning of oxides from depleted uranium surfaces will be undertaken. This work is sponsored by the Oak Ridge Y-12 Plant.

Another apparatus, Fig. 4, is designed to be mounted on a robotic arm for stripping epoxy-based paints from aircraft. This unit uses a lightweight 15-HP brushless DC motor with a 14-in (0.35-m) wheel. The weight of the accelerator is kept below 75 lb for compatibility with the robot. This unit will accelerate CO_2 pellets up to 1,300 ft/s (400 m/s) at a throughput of 400 lb/h (180 kg/h). A commercial CO_2 micro-pellet fabrication machine will be used to feed the centrifuge. Tests performed on our research apparatus showed that epoxy/urethane paint removal rates 1 to 2 ft^2/min might be achievable with the apparatus. This work is being sponsored by the U.S. Air Force, Warner Robins Air Logistics Command.

4. TEST RESULTS

Tests performed with the research device showed that at high speeds CO_2 pellets could be used to etch a variety of surfaces. Figure 5 shows some results for solid argon pellets. At 1500 ft/s (450 m/s) hard, black oxide coatings were removed from steel samples. A threshold velocity of 656 ft/s (200 m/s) was required to remove mil-spec epoxy/urethane paint surfaces aluminum surfaces. Prewarming the painted surface to modest temperatures was found to enhance paint stripping efficiency, Fig. 6. A variety of samples such as would be found in decontamination and decommissioning projects were cleaned. These included removal of paint from steel siding, the removal of zinc coatings from galvanized steel, and the removal of rust from weathered construction steel. At speeds of 1600 ft/s (500 m/s), hard alumina ceramic material was eroded. The ability to precisely control the pellet speed of the centrifuge system should make it a versatile and attractive device for a variety of tasks.

5. CONCLUSION

Centrifugal cryoblasters show good promise for meeting a variety of industrial cleaning, decontamination, and surface preparation needs. Cleaning of a wide range of materials from different surfaces has been demonstrated. The process has been found to be highly efficient. Development of lightweight units is in progress which can be used in routine industrial applications.

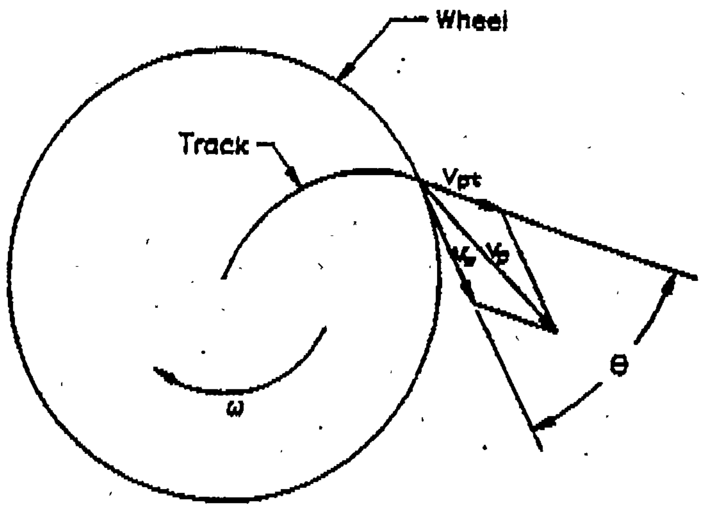

Fig. 1. Rotating centrifuge wheel geometry.

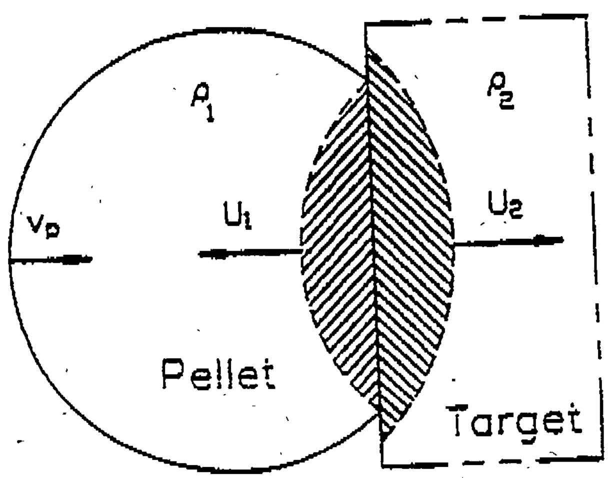

Fig. 2. Pellet impacting surface.

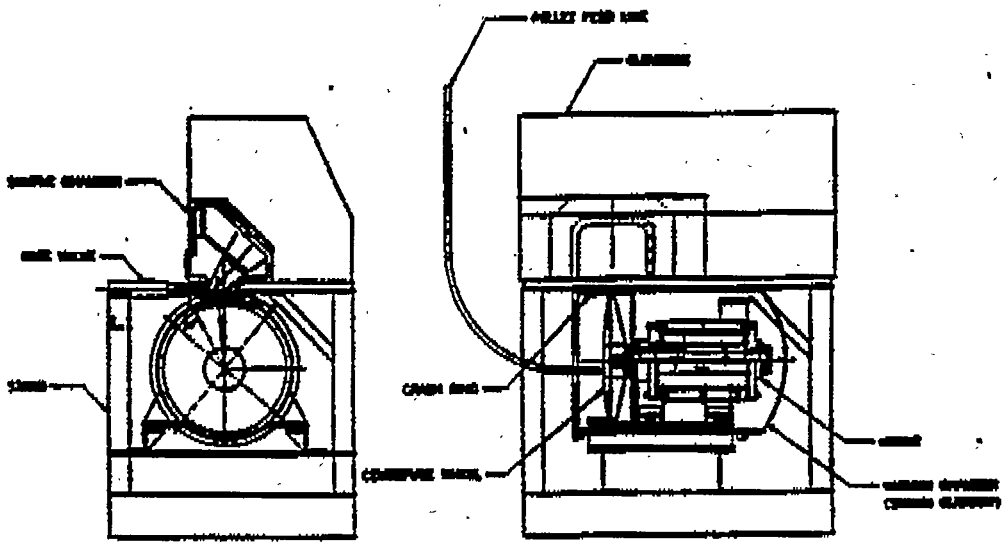

Fig. 3. Stationary centrifugal cryoblaster for cleaning tests of contaminated materials.

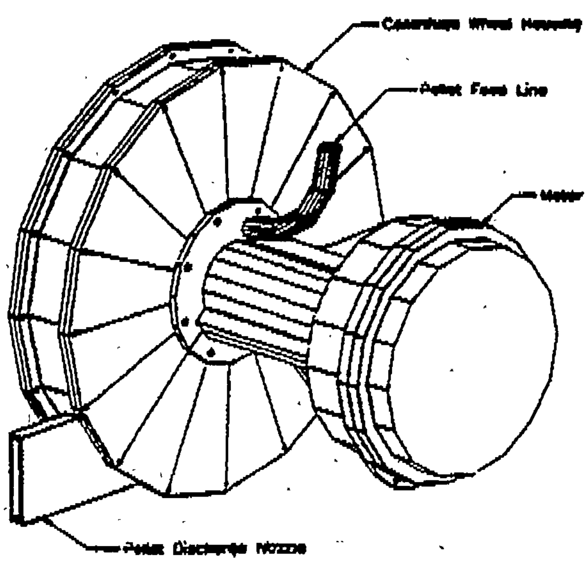

Fig. 4 Robot-compatible centrifugal cryoblaster.

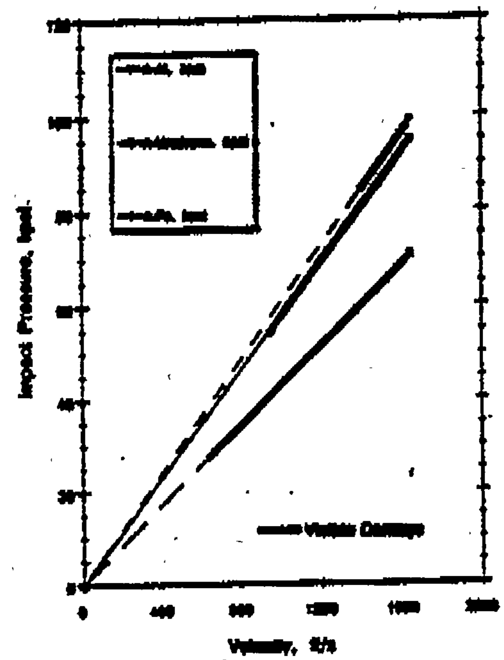

Fig. 5. Solid argon pellet results on various surfaces.

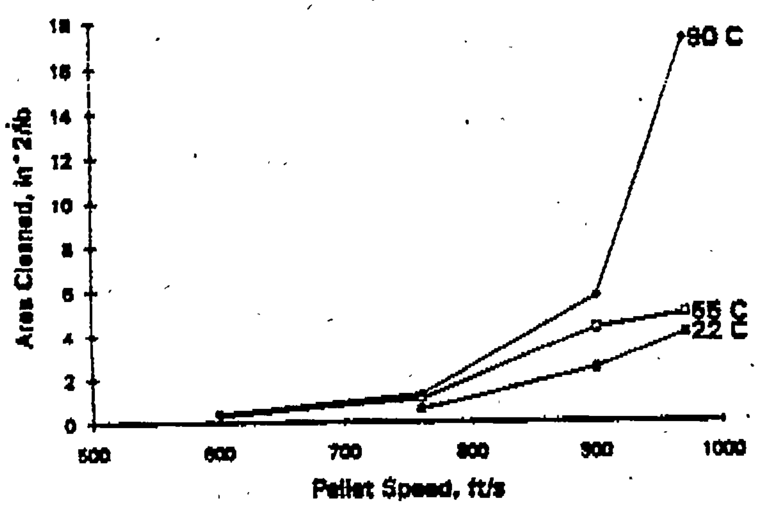

Fig. 6. Effect of temperature on CO_2 pellet paint stripping efficiency for F-15 samples.