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Paper

APPLICATION OF ICE POWDER IN BIOMEDICAL AND FOOD INDUSTRIES

K. Kluz, E.S. Geskin
New Jersey Institute of Technology
Newark, New Jersey, U.S.A.

ABSTRACT

The objective of this work is to investigate the applicability of ice powder blasting in material processing and tool cleaning in biomedical and food industries. The laboratory scale prototype of the sought device was constructed and tested for cleaning and peeling of fruits, vegetables, and animal skin tissue. In the course of performed experiments it has been shown that the air-ice particle stream can be generated and applied for processing of bio materials and food. Potential applications and constraints of ice blasting technology are discussed.

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1. Introduction

One of the main applications of the jet technology is surface preparation. For example, high pressure water jets became a principal depainting tool. However, potential ice-jet applications for the surface processing are far from being exhausted. Currently, the main jet use in surface processing involves treatment of comparatively hard shell targets, such as civil structures, mechanical parts, ship decks and hulls, etc. At the same time the surface processing of "soft" targets, such as biological tissues or food products is not addressed adequately. There are all reasons to believe that the volume of these applications is at least comparative to the volume of existing ones or even probably exceeds it. Moreover, the use of ice-jet blasting will enable us to find low cost alternative solutions in the medical procedures like: surgery, wound management, or skin treatment.

Due to shear production volume and existential importance, food processing constitutes one of the major industrial technologies. At the same time the diversity and low predictability of the shape of raw materials combined with extremely high requirements for the product quality determine process constrains. These constraints are illustrated by the technology of vegetable peeling. While there are no two identical objects, peeling must bring together high rate of processing with minimal material loss and damage. The mechanical removal, which is the most common case of peeling technology, requires application of relatively expensive and complicated devices [1-3]. The peeling techniques also involve the use of chemicals [4] and steam blasting.

Ice blasting has a potential of becoming the major peeling technology. This technology involves formation of ice particles, entrainment of these particles by an air stream and blasting the target by the generated mixture. Our previous study showed that blasting by air-ice mixture enables us to remove surface deposit from highly sensitive targets with no surface damage [5-11]. Thus it is possible to use this stream for peeling potatoes as well as other vegetables. Due to process simplicity and low cost of equipment, ice blasting could be more effective than mechanical or steam peeling. The energy consumption of water sublimation is almost six times less than the energy needed to convert water into saturated steam. Moreover, the speed of the vapor depends on the stagnation pressure which is a function of the steam temperature. The correlation between these two variables complicates process control. Conversely, the temperature and erosive ability of the ice-air stream can be controlled independently. Thus, at least in the principle, ice blasting enables us to reduce the cost of peeling and improve control of the process. Of course, blasting is not only possible application of ice abrasive capabilities in food processing. The ice abrasion, can be used, e.g., in the fluidized bed type vegetable processing. Similar procedure was suggested for cleaning of glass fragments [12].

Required purity of food and bio-medical products can be attained only by sufficient cleanliness of the tools, which have any contact with the processed material. Inadequate cleaning brings losses and might result in fabrication of contaminated products. The desired cleanliness of food processing facilities is commonly attained by water or steam blasting and by the use of chemicals. The former involves the large water consumption, while the later requires the use of chemical cleansers. Both of the illustrated technologies involve generation of significant pollution streams, which require additional, high-priced treatment. By contrast, the ice blasting generates practically no off products and brings about no work piece pollution. In addition the process is simple and inexpensive and thus available for any, either large or small food processor. The most important however, is the feasibility to attain the highest cleanliness of food at the acceptable cost and productivity.

Precision ice blasting can also be used as a medical tool. One of its immediate potential applications is improvement of the skin appearance. From the beginning of time, people suffering from facial scarring have searched for ways to improve these imperfections. Thanks to refinements of a number of dermatologic surgical techniques, there are several safe, effective procedures available today to reduce facial scarring, including dermabrasion or microdermabrasion. During dermabrasion, or surgical skin planning, the dermatologic surgeon freezes patient's skin, scarred from acne, chicken pox or other causes. Then the doctor mechanically removes or "sands" the skin to improve the contour and achieve a rejuvenated appearance as a new layer of remodeled skin replaces the damaged skin. The new skin generally has smoother and refreshed appearance. The results of this procedure are generally quite remarkable and long-lasting. It is quite obvious that the ice blasting can also be used as a dermatological tool. Ice abrasives are chemically neutral, clean and cause no pollution both to the surrounding and treated object. The process residues are limited to a small amount of moisture. The procedure is simple and inexpensive. The principal advantage of the ice blasting, however, is the possibility to control precisely the erosion rate and skin temperature.

The previous study of the ice blasting [5-11] showed effectiveness of the application of this technology for processing various products like: semiconductors, electronics, marble, polished metal, etc. Biomedical and food processing applications, however, require much higher process precision and reliability than purely engineering applications. The interruption of the continuity of meat cleaning, e.g., might result in product poisoning while the unexpected change of the ice flow rate during the surgery can damage the skin. The objective of this study is to demonstrate feasibility of the application of ice blasting in food processing and dermatology. The existing systems for ice powder generation and ice-jet formation were improved and series of experiments involving vegetable and fruit peeling, meat cleaning, and skin abrasion were performed. The results of treatment were visually inspected. The evaluation involved assessment of the process completeness as well as identification of any surface damage. The performed experiments show that, at least in the principle, the abrasive ice blasting constitutes an effective tool for processing organic objects.

2. Experimental Setups

In order to investigate the desired applications of ice blasting three setups have been designed and built. The principal element of experimental setups was the ice generation device termed Ice Boiler and presented in Figure 1.

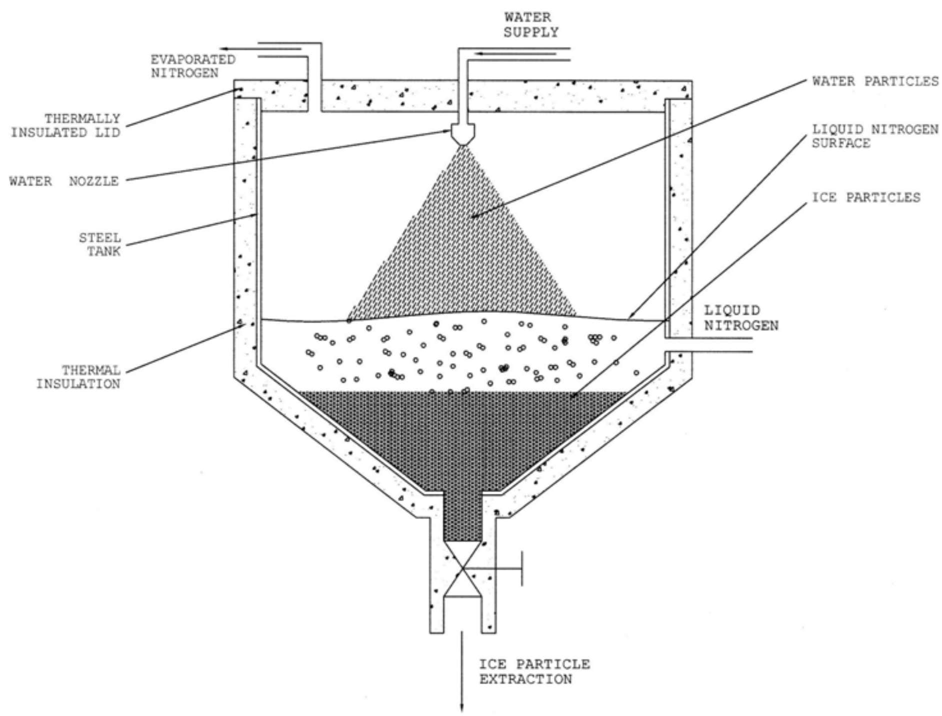

Figure 1 Ice Generation System Description

The integral component of the ice boiler was a simple insulated tank with zinc plated steel lining. The main purpose of the boiler was to freeze water droplets and thus generate ice particles. The tank was filled with approximately 5 kg of liquid nitrogen. The upper lid of the boiler equipped with the mist nozzle generated the water spray at the desired rate of 100 ml/min and droplet size of ~15 μm. When the water spray entered the tank droplets solidified almost instantaneously. Heat rejected by water in the course of solidification was absorbed by nitrogen. This resulted in nitrogen boiling. As the consequence of this phase change nitrogen boiled and evaporated. The specific nitrogen consumption is determined by the equation:

$$\frac{\overset{\circ}{m}_{nitrogen}}{\overset{\circ}{m}_{water}} = \frac{h_1 - h_2}{h_3 - h_4} = 2.84 \qquad \textbf{(1.1)}$$

Where:

$\overset{\circ}{m}_{nitrogen}$, $\overset{\circ}{m}_{water}$ - mass flow rates of nitrogen and water

h_1, h_2 - enthalpy of water entering and leaving the system

h_4, h_3 - enthalpy of nitrogen leaving and entering the system

Tank was vented and operated at atmospheric pressure so the excess of nitrogen vapor escaped the chamber. The ice particles have higher density than liquid nitrogen (930 vs. 809 kg/m^3) and thus they descended and congregated on the bottom of the tank. Then the ice particles were extracted from the tank and used as a blasting medium. Due to the extremely high rate of water solidification in the nitrogen bath, the size of the ice particles is determined by the size of injected droplets. Because the selected nozzle generated comparatively uniform droplets, the uniformity of particles was also assured. Thus size of the particles and the rate of the ice generation were precisely controlled by injection conditions. The size of the particles generated during the performed experiments was in the range of 15-20 microns. Improvement of the nozzle design will enable us to generate micron and perhaps submicron particles.

The generated particles are removed from the boiler manually and transferred to a blaster. Two versions of ice blasters are shown on Figures 2 and 3.

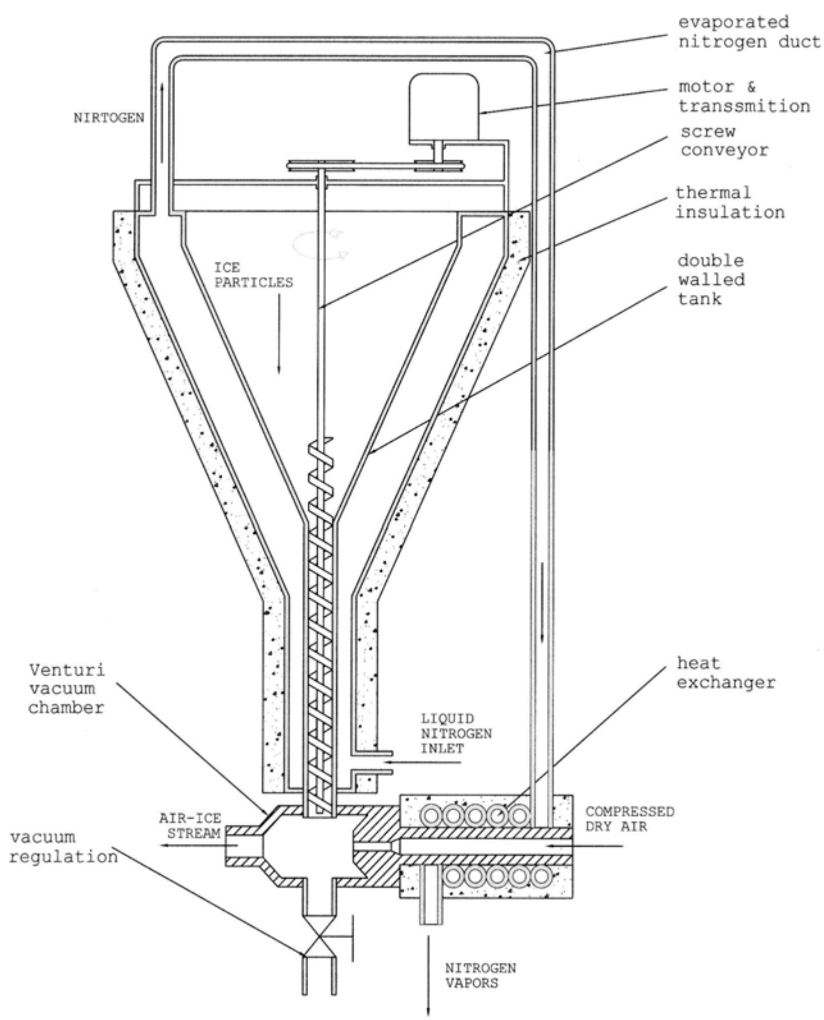

Figure 2 Ice Blaster with Screw conveyor

The ice blaster (Fig. 2) is consisted of the hopper equipped with a low rpm screw conveyor, double shell heat exchanger and vacuum chamber. Ice particles were supplied into the hopper and transferred by the conveyor into the negative pressure chamber where they were entrained by an air stream. As a result, the ice-air jet was formed.

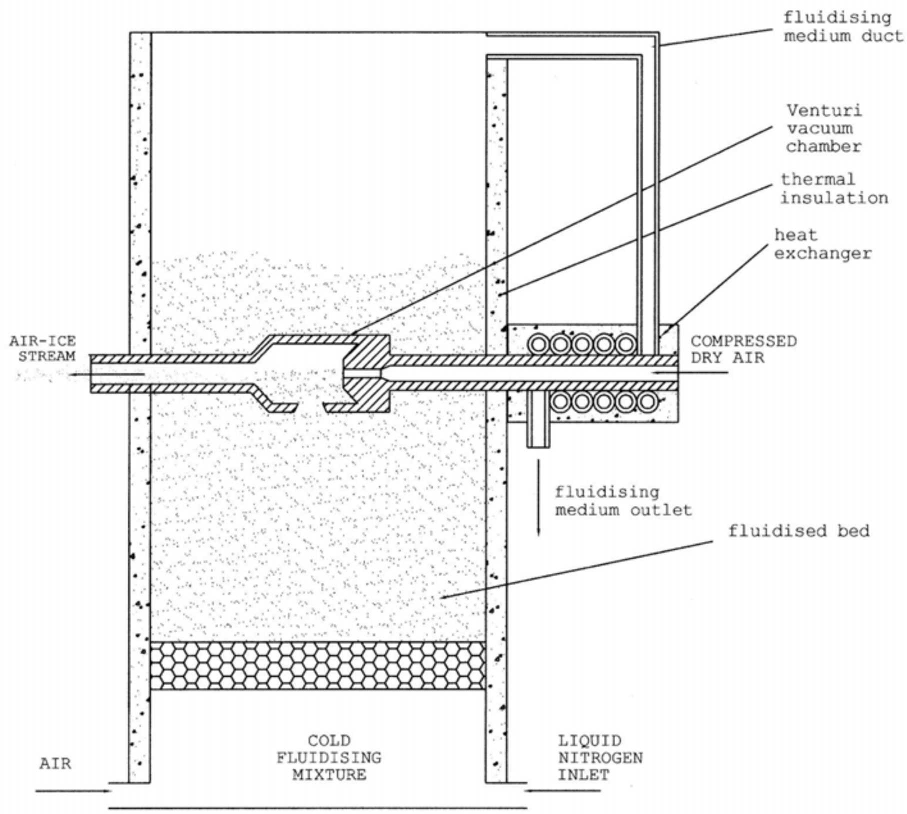

Figure 3 Ice Blaster with Fluidized Bed

The principal part of the blaster (Fig. 3) was a fluidized bed comprising ice particles and a low temperature air-nitrogen mixture. The mixture generated was entrained by high speed air in the vacuum pump located in the fluidized bed. The position and design of the vacuum pump assure the steady feed rate of mixture into the nozzle. The advantage of this particular system is the absence of moving parts.

Despite the fact that the devices (Figs 1-3) were manufactured at the marginal financial cost, they performed well and supported the conducted study. Fine, uniform ice particles (Fig.4) were reliably generated at the desired rate and blasted.

Figure 4 Generated Ice Particles

Figure 5 Nozzle with Visible High Speed Ice Jet

The ice stream generated by the setups (Figs. 1-3) was directed by a manually guided nozzle (Fig.5) at the samples in question. The blasting resulted in target peeling or cleaning. The treated surface was subsequently evaluated visually and the completeness of material removal and the induced surface damage were determined. Both, mechanical and thermal effects of the blasting were evaluated. The operational parameters of the blasting were as follows:

- ice flow rate: 150 g/min
- ice particle diameter: 15-20μm
- supplied air pressure: 5.5 bar
- air temperature : 15°C
- ice particle temperature: -170°C
- nozzle diameter: 5 mm
- standoff distance: 0.05-0.1 m

The experiments involved peeling of the vegetables and cleaning of kitchen utensils. The effect of ice blasting on chicken skin was also investigated.

3. Experimental Results and Discussion

The first experiment involved potato peeling. Red and Idaho potatoes were partially covered by a protective tape and subjected to ice blasting. The skin in the unprotected region was removed completely (Figs 6 and 7). No excessive material removals as well as temperature affected spots were noticed. Similar results were obtained in the course of carrot peeling (Fig. 8). Finally, peeling of the apple skin was examined (Fig.9). While the apple texture tends to deteriorate rapidly, no deterioration as well as excessive material removal was observed.

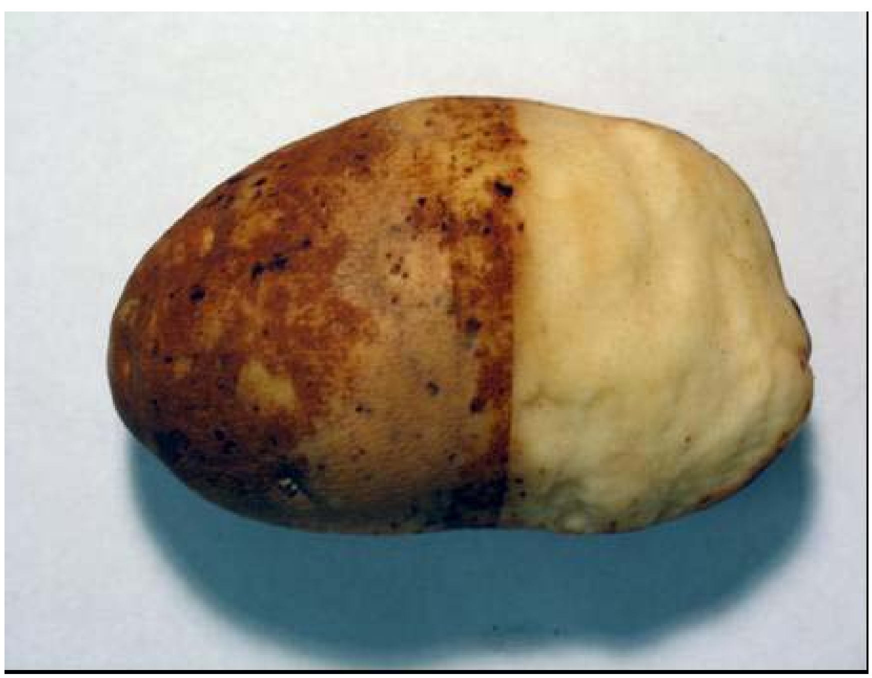

Figure 6 Idaho Potato after Partial Peeling

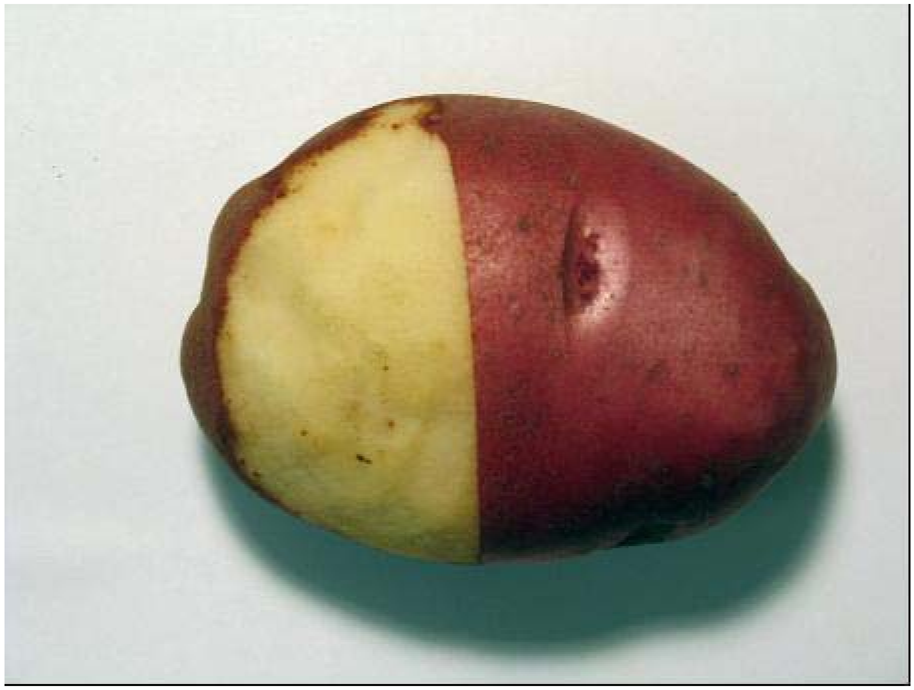

Figure 7 Red Potato after Partial Peeling

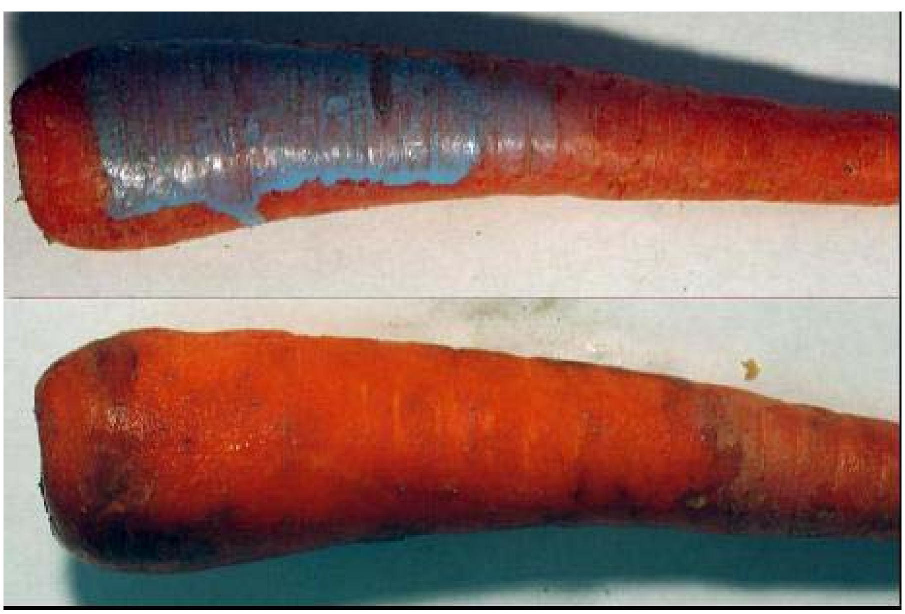

Figure 8 a) Carrot Contaminated with Oil Based Paint
b) Carrot after Cleaning;

Figure 9 Apple after Ice Jet Peeling

Another experiment involved extensive cleaning of the chicken skin (Fig.10). In this experiment part of the chicken was covered by oil based paint. Ice blasting resulted in complete paint removal. The superficial skin (epidermis) was also removed. No signs of damage to the deeper skin layers were observed. Moreover, the processed area gained fresh and healthy appearance. Due to various limitations there was no extensive research conducted on human skin. However, based on the previous experiment, authors strongly believe that the ice blasting can be successfully used in dermatological dermabrasion. A superficial skin (epidermis) would be removed at very light pain or rather inconvenience. Right after the experiment the skin would acquire pink color and light inflammation. In couple days after treatment all change in the skin appearance should disappear. The achieved results should be comparable to the existing methods of dermabrasion. The strength of treatment would depend on four parameters: time of the ice blasting, distance between the nozzle and the skin, rate of ice delivered, and pressure supplied.

The next experiment concerned depainting of stainless steel (Fig.11). The viability of utensil and food processing equipment cleaning was demonstrated.

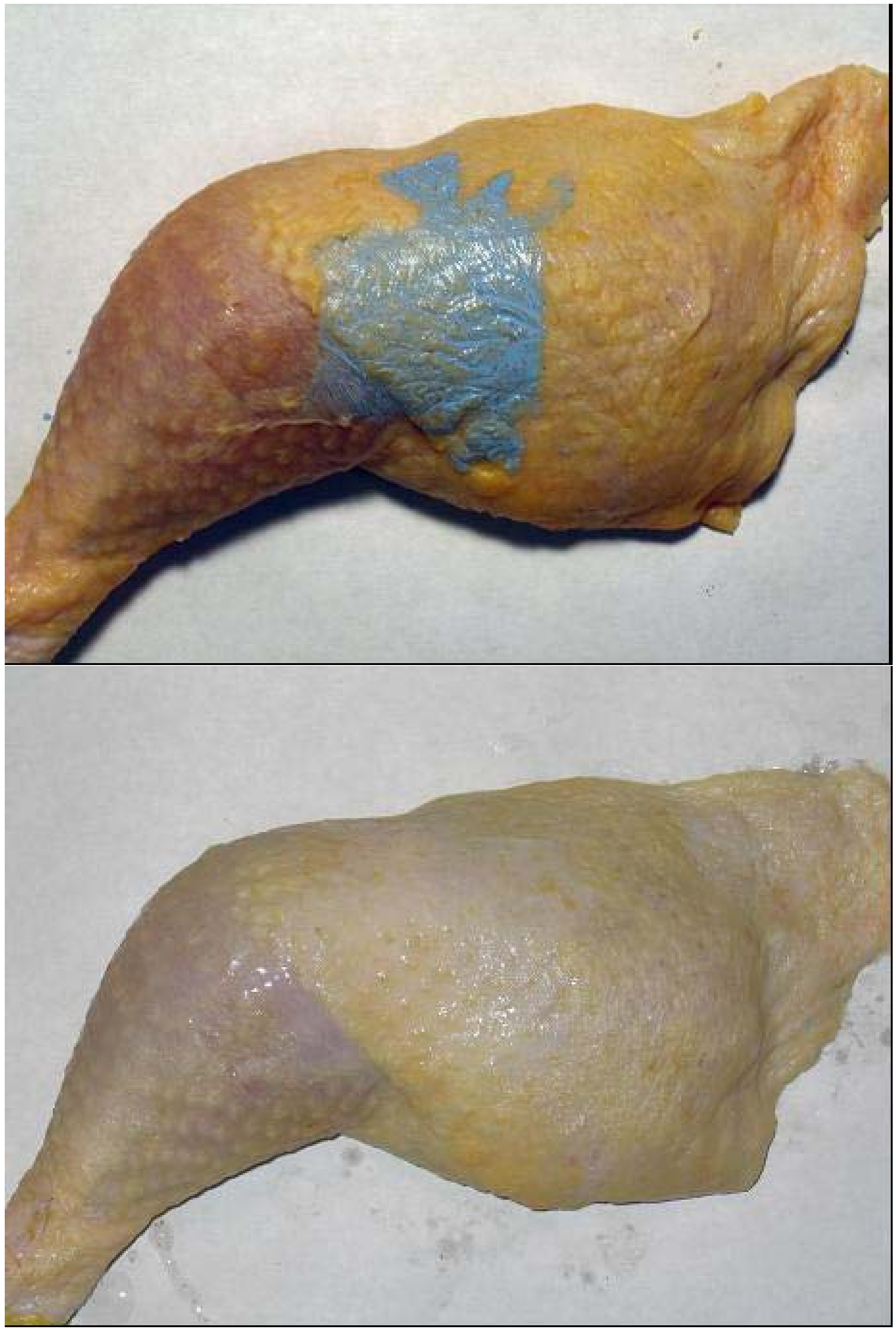

Figure 10 a) Chicken Leg Contaminated with Oil Based Paint
b) Chicken Leg after Cleaning Paint Removed Together with Superficial Skin Tissue

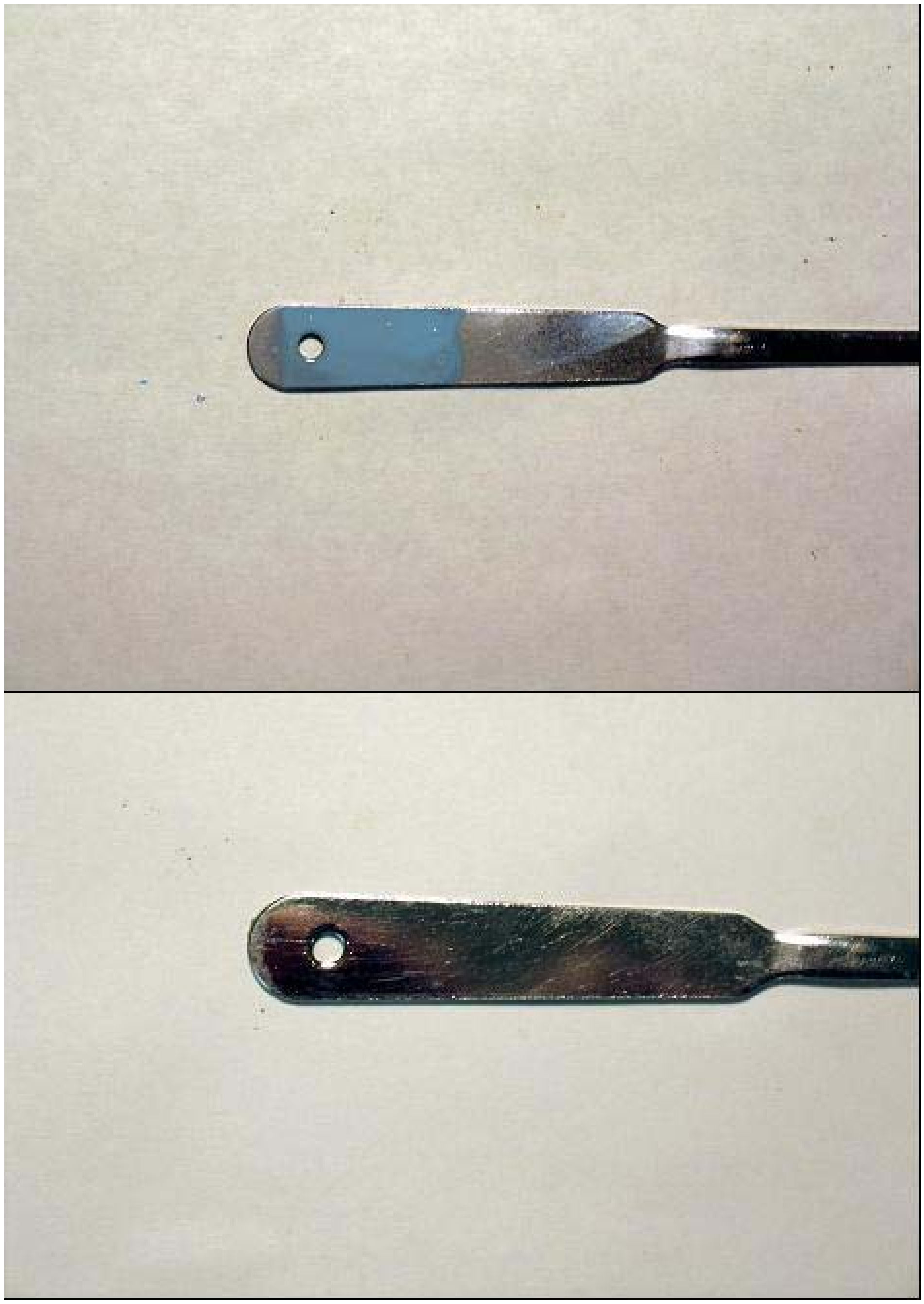

Figure 11 Stainless Steel Knife Before and After Cleaning

4. Concluding Remarks

The feasibility of use of ice powder blasting in the food industry and dermatology was demonstrated. The facility for ice powder formation and blasting is inexpensive, flexible and its operation is relatively simple. The apparatus can be designed for a medical office, restaurant or food processing plant. The new, redesigned system (currently under construction) will include all major features of the setups Figs 1-3. Moreover the device will be much more reliable and user friendly; however it will maintain simplicity and flexibility of the presented setups. The size and speed of ice particles determine the erosion rate, which can be readily controlled by the size of water droplets and supplied air pressure. Due to these features and total chemical neutrality, the ice-air jet can be successfully utilized as a precise surgical tool in the treatment of soft human tissue as well as a cleaning and peeling medium in food processing industry.

At the initial stages of the process development, water jets were used as a material removal tool. The next step involved the addition of abrasives and polymers to the water stream. Another advance was the application of other than water fluids, e.g. liquid nitrogen. The study conducted in Water Jet Laboratory at New Jersey Institute of Technology shows that the ice based systems might constitute the next enhancement in the technology of abrasive blasting.

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