AIR AS A SUBSTITUTE FOR WATER IN FOOD PROCESSING

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Availability is a major reason for using air in place of water for heat transfer and materials handling operations in the food plant.

Physical properties of air and water are shown in Table 1 for comparison. The viscosity, thermal conductivity, specific heat, and density of air do not change significantly over the range of temperatures where air could substitute for water in the food plant. The viscosity of air is approximately 1/50 that of water. Although this is an advantage, the differences in thermal properties and 80-fold density difference between air and water require that special equipment be used if air is to be substituted for water.

Table 1. Physical Properties of air and water at ambient temperature (70°F)

Property	Air	Water
Specific heat BTU/lb °F	0.24	1.00
Thermal Conductivity BTU/hr-ft^2-F/ft.	.015	0.36
Density lb /ft^3	.075	62.3
Viscosity lb /ft hr (centipoises)	.0435 (.018)	2.38 (.981)

The chemical composition and microbiological content of air must also be considered. Oxygen can react with food components to cause discoloration, flavor changes, and loss of nutritive value. The moisture content of the air will influence rate of evaporative weight loss from food materials whenever air is in contact with the product. Since the moisture holding capacity of air is a function of temperature and pressure, the potential for evaporative loss must be determined under specific operating conditions. Fortunately, relatively small quantities of water will saturate air under normal food processing conditions. At 70°F, air containing about 1.5% moisture (weight basis) is saturated.

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Air may contain up to 1.5 million particles 0.3μ or larger per cu. ft. While total particle content is of concern, the microbial content of the air is a major consideration, due to the potential for product contamination.

Foreign chemicals that could contribute to off-flavors or otherwise contaminate the food must be eliminated from any process air used in direct contact with food materials.

Except when foreign chemicals are present, it may be easier to clean process air for use, disposal, or recycling than it is to clean water for the same purposes.

Current applications of air in various food processing operations are described below.

Cleaning and Separation

Mechanical harvesting of seasonal crops has caused great changes in the cleaning requirements for raw materials. The mobility of mechanical harvesters precludes the use of large amounts of water for in-field cleaning and trash removal. Yet mechanical harvesting can result in large amounts of trash, broken product, and dirt being delivered to the processing plant.

Air cleaning has proven effective for trash removal and the separation of loose soil and other low bulk density materials. Air separation is basically a form of pneumatic transport. Pneumatic transport for cleaning will be effective only if the physical properties of the unwanted material differ significantly from those of the food material being cleaned.

Zenz and Othmer (1960) describe the conditions affecting the free-fall velocity of particles in upward moving air. The drag force is proportional to the dimensions, shape, and velocity of the particle and the density and viscosity of the fluid. In general, air separation equipment is useful in removing waste material differing from food material in shape, size, and surface roughness, since density variation is not great among the edible and inedible portions of plants. Air velocity is selected to exceed the settling velocity of unwanted stems, leaves, and trash, while allowing the more regular food particles to remain as a fixed bed. Air quality is of minimum concern in harvest and post-harvest raw product cleaning. Mechanical motion may be used to improve the efficiency of air separation providing no product damage takes place.

The removal of smear soil, insect fragments, plant exudates, or other incidental contaminants by means of air scouring alone does not seem feasible at the present time. The energy needed to release this type of soil from the surface of the food can best be supplied by mechanical means combined with a limited amount of water or possibly another liquid. Krochta and Bellows (1974) discuss minimum water cleaning approaches.

Pneumatic Transport

Pneumatic transport is widely used for handling small dry food particles, powders, packaging materials, frozen foods, and more recently raw and blanched particulate foods. Successful applications have overcome the problems of product damage, microbial contamination, dehydration, product delivery, and air cleaning for discharge or recycling.

Pneumatic transport of high moisture particulate foods presents several major materials handling problems not encountered in conventional water fluming. Water cushions, suspends, and continuously cleans the particles and the conveying equipment. Moist food particles can be damaged during pneumatic transport by impacting in the transport pipe at bends and during discharge. Each time the particle contacts the pipe surface a layer of food material may be deposited. This food material is subject to microbial growth which will further contaminate the food and the downstream transport tube.

Although the system may be self-cleaning in operation, shutdowns must be followed by a thorough washing to reduce microbial buildup. This may be difficult to accomplish without special provisions for cleaning remote parts of the system. Provision must be made for discharging the product from the system and possibly cleaning the air. Positive air locks, cyclone separators, or other mechanical systems can represent an extensive investment and a complex cleaning problem.

With these problems in mind, Wolford (1972) describes microbial studies on negative air pressure conveying (NAPC) systems for transporting blanched cut vegetables in frozen food plants. Fig. 1, taken from this article, illustrates the basic system. Blanched peas, cut green beans, cut corn, lima beans and diced carrots can be conveyed successfully. The system consists of 4- to 6-in diameter tubes which are open at the inlet. The transport tubes are attached to a cyclone separator while a vacuum pump is used to establish air flow. The primary advantage of the system is to reduce water usage normally required by hydraulic conveying. Pneumatic transport may have an economic advantage over other mechanical means for long distance transporting. A plant handling 5 tons of peas per hour can

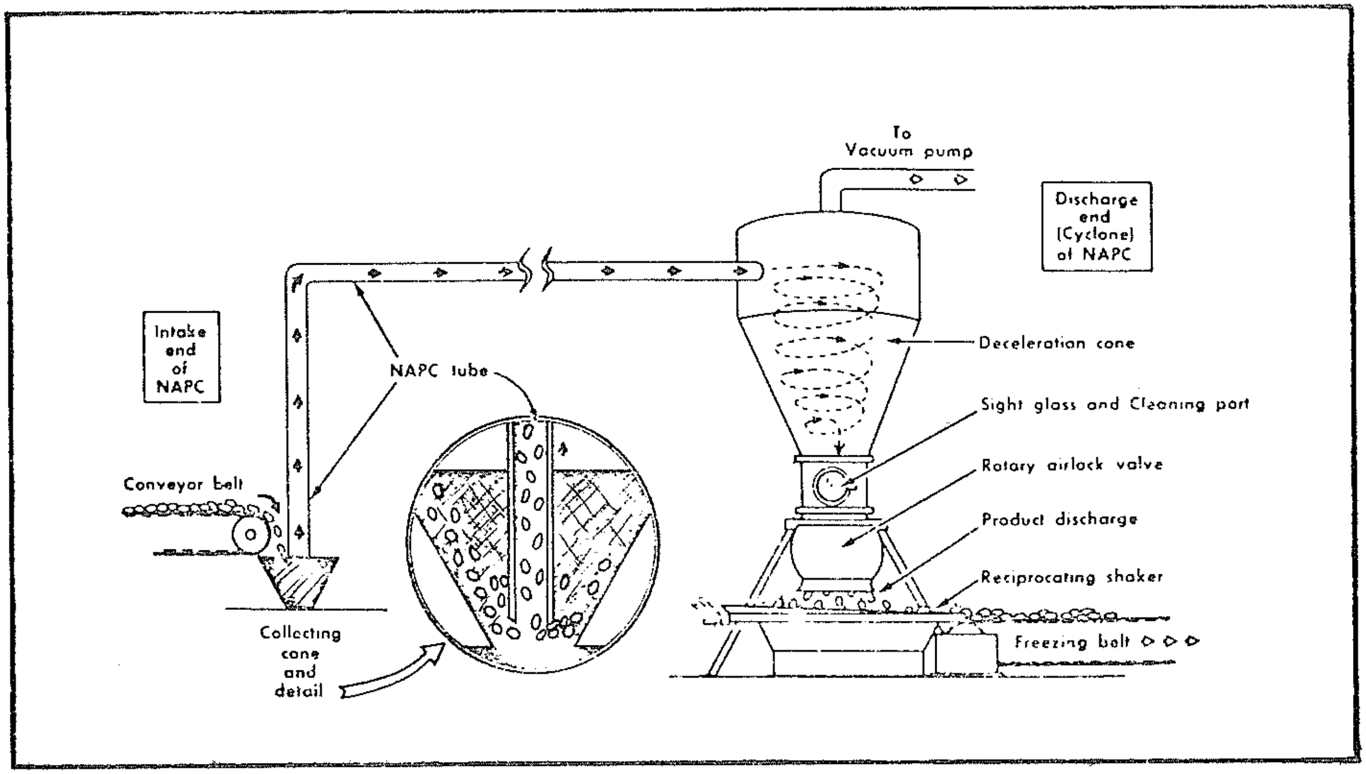

Figure 1. Negative Air Pressure Conveying System (Wolford 1972)

save the use of 20,000 gallons of water per hour. Wolford (1972) does not mention power requirements and relative capital costs. A rigid sanitation schedule must be maintained to minimize microbial buildup.

A processor faced with the need for effluent reduction through flume replacement should consider pneumatic conveying as an alternative to reduce length of flow streams and mechanical transport by vibrating conveyors or belts. Effective sanitation procedures must also accompany the use of any of these pieces of equipment.

Heating and Cooling

While the potential is great for reducing water use by substituting air in heating and cooling applications, lower values of heat capacity and density greatly reduce the effectiveness of air. A volume of air over 3,000 times as great as water is needed for equal heating or cooling effectiveness. Heat transfer equipment using air is significantly larger than that using water. This becomes obvious in Fig. 2, where surface heat transfer coefficients in a tubular heat exchanger are compared at various flow rates (pressure drops). Water is more effective by a factor of 30 at 15 lb. force per ft^2 pressure drop. No mass transfer is assumed to take place in these considerations. Heating with steam-air mixtures and evaporative cooling, where mass transfer does take place, will greatly increase the rate of heat transfer while minimizing water use. This can be discussed in relation to specific processing applications.

Blanching

Blanching in air-steam mixtures, in steam-combustion product mixtures, and in air alone has been reported by Mitchell et al. (1968), Ralls et al. (1973) and Brown et al. (1972), respectively. All of these methods are essentially effluent-free; however, as the ratio of steam to air is reduced, more and more product dehydration takes place during the blanching process. Brown et al. (1972), using a centrifugal fluidized bed with air velocities between 1500 and 3100 ft/min., and air temperatures between 220°F and 260°F, were able to blanch carrot dice in 8.4 minutes at the minimum conditions and 2.1 minute at the maximum velocity and temperature used. Weight reductions of the order of 50% were encountered under these blanching conditions. Mitchell et al. (1968) indicated that blanching in a steam-air mixture was equivalent to water blanching for peas, while the hot gas blancher concept developed by Ralls et al. (1971) has been used successfully to blanch snap beans for canning.

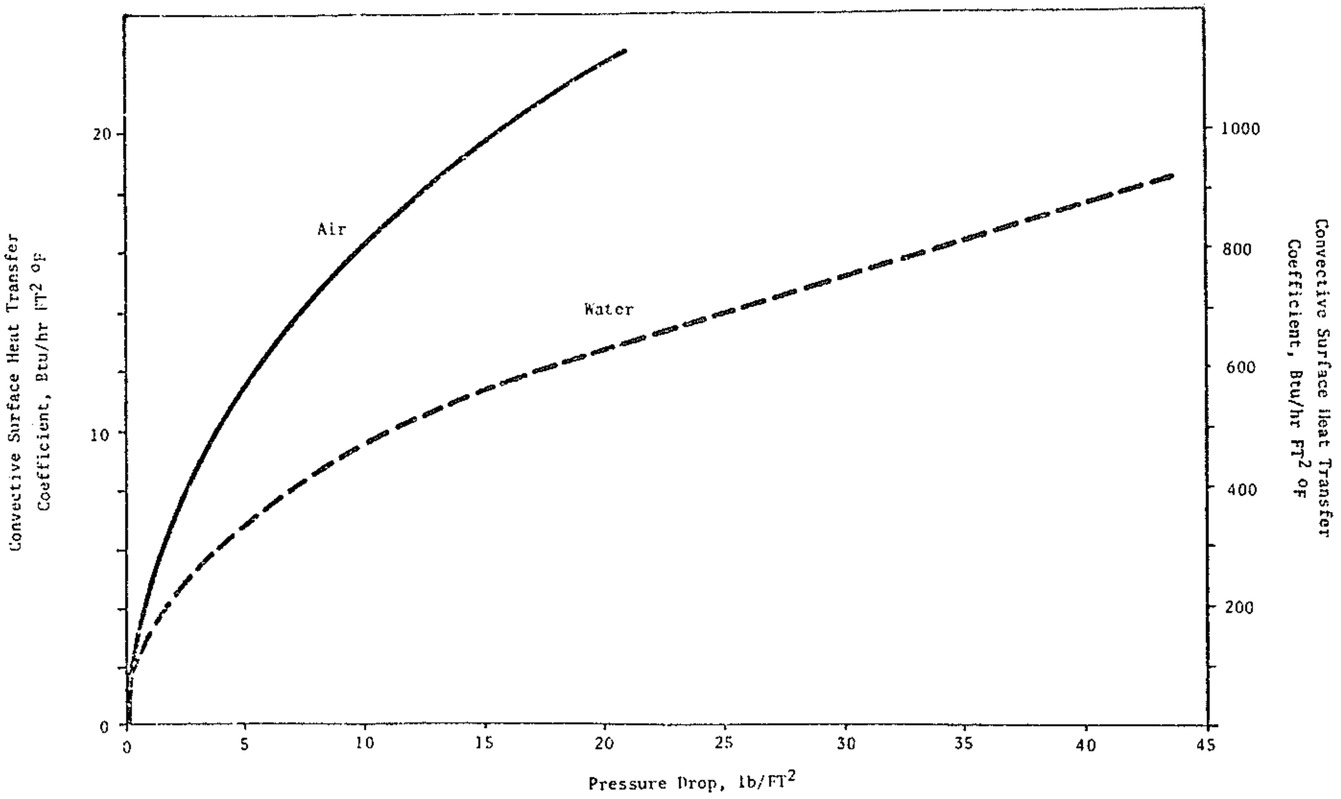

Figure 2. Surface Heat Transfer Coefficients vs pressure drops for air and water in a 2-in diameter tubular heat exchanger.

Can Sterilization

Methods have been developed to use air or hot gases as a substitute for steam or water in thermal processing. These include direct flame heating, high velocity air heating, and the use of deep fluidized beds to achieve over-pressures necessary for larger containers, Casimir (1970) cites the work of Ecklund and coworkers who developed a hot air can sterilizer in Sweden. Rolling motion, together with air at 293°F circulating at 33 ft/sec., gave a center temperature of 253°F in canned milk in 15 minutes.

Flame sterilization of cans, originally proposed by Beauvais et al. (1961), has achieved commercial use world-wide with small containers for non-acid foods and with larger containers for acid products. Small containers allow processing at internal can temperatures above 212°F since they can withstand pressures up to 15 psig if properly designed. Larger containers can only be heated to temperatures at or slightly above 212°F.

A novel fluidized bed retort has been described by Jowitt and Thorne (1971) and Thorne and Jowitt (1972). Heat transfer is increased by heating and cooling the cans in a fluidized bed of sand or other granular high density material such as hematite. Air pressures corresponding to saturated steam processing temperatures are achieved by the use of fluidized beds of sufficient depth.

Results show that process times are only slighly longer than those necessary for saturated steam processing and contrary to expectations, can abrasion from the fluidizing medium is negligible.

Cooling

Air is most effectively used in cooling in conjunction with water by direct contact evaporative cooling of food materials. Indirect evaporative cooling and cooling towers are not considered here. Weight loss is always a problem during evaporative cooling of processed foods since the cooling air can never have a water vapor pressure greater than that of the product surface.

Considerable work is needed to determine the best conditions for evaporative cooling in terms of product weight loss, effluent strength and volume, and equipment design. Currently, a number of processors are using fluidized beds for cooling vegetables after blanching and prior to freezing. Little data are available on weight loss resulting from evaporative cooling. However, Bomben et al. (1973) showed that evaporative weight loss for any product was closely related to the amount and method of water application during cooling. Flume cooling and spray cooling were studied.

Coffelt and Winter (1973) studied the effect of air velocity, relative humidity, and temperature on the rate of cooling of blanched potato cubes. Results showed that air at 70°F and 50% relative humidity and having a velocity of about 10 ft/sec. could cool 11/16-in. potato cubes from 190°F to 90°F in 5 minutes. Higher relative humidities reduced the effective rate of cooling slightly, while higher air velocities improved cooling rates. Air-water sprays gave cooling rates equivalent to those of air alone. Unfortunately, no data were taken on weight loss for each cooling condition. Water sprays applied at the correct time during cooling would reduce some of the evaporative weight loss (Winter, 1973).

Summary

Air appears to be a useful alternative fluid to water for certain cleaning, transport, and heat transfer operations. Data available in the literature are of limited use in evaluating the economic benefits of installing, for example, a pneumatic transport system in preference to mechanical conveyors or evaporative vegetable cooling over flume or spray systems.

While reduction in water use and hence effluent volume is an immediate benefit, savings in product solids lost through leaching and reduced capital costs are possible.

Optimum applications for air appear to be: precleaning; transport over long distances; and in conjunction with a small quantity of water, evaporative cooling.

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