Table 1 .... Relation of Initial Fruit Temperature and Length of Cooling to the Amount of Cooling Obtained With a 2-unit, Commercial, Mechanically-Refrigerated, Flood-Type Hydrocooler[a,b]

Test No.[b]	Average Water Temp, F	Average Fruit Temp, F: Before Hydro-cooling	Average Fruit Temp, F: After Hydro-cooling	Time in Cooler, Min	Average Cooling Obtained, F deg
1	33	78	55	11	23
2	34	81	61	11	20
3	34	84	52	18	32
4	34	80	53	17	27
5	34	63	45	17	18
6	34	65	45	17	20
7	35	67	49	17	18

[a] All tests with 2-in. and larger Brackett peaches brushed and packed in ¾-bushel baskets.
[b] Each test is an average of 5 observations.

quately cooled at any of the exposures emphasizes that the longest time allowed in the cooler was insufficient for good pre-cooling.[8]

The conventional hydrocooler is a semi-portable unit, usually from 30 to 40 ft long and 4 to 6 ft wide, which contains a water supply tank, a conveyor for moving the product through the unit, a perforated sluice box or battery of spray nozzles above the conveyor, and high capacity pumps for circulating the water. Refrigeration may be furnished either by ice in the water tank, or by mechanical units with direct expansion or brine coils in the tank.

When hydrocooler water is recirculated for some time, as is usually the case in mechanically refrigerated units, there is certain to be some accumulation of decay-producing organisms. The addition of mild disinfectants such as chlorine or approved phenol compounds will reduce the build-up of bacteria and fungus spores, but will not kill infections already in the products or sterilize either the water or the product surfaces. The principal problem in connection with the use of approved chemicals is the maintenance of uniform concentrations, particularly in ice-refrigerated equipment, because of the constant dilution from the melting ice.

Cooling with Vacuum

Following initial semi-commercial trial on a few lots of California lettuce in 1947, vacuum cooling was in extensive use in western states by the early 1950's. Almost all of the some 70,000 carlots of lettuce shipped each year from California and Arizona are now vacuum cooled. In recent years some eastern lettuce has also been vacuum cooled. There is increasing use of the vacuum process for precooling celery, cauliflower, green peas, and sweet corn.[9,10,11,13]

Vacuum cooling is simply cooling by evaporation. Commodities to be cooled are placed in a large steel tube or chamber which can be hermetically sealed and rapidly evacuated. When the atmospheric pressure within the chamber has been reduced to the boiling point of water at a temperature corresponding to the initial temperature of the product, evaporation of moisture begins. As the pressure is reduced, evaporation continues still further until at a pressure of about 4.6 mm of mercury, a commodity temperature of 32 F will be reached if evaporation continues for a sufficient time at that pressure.[12] Each pound of water evaporated from the product removes approximately 1060 Btu, as compared with 144 Btu removed by melting 1 lb of water from ice.

Two methods presently are used to produce the vacuum. In the type first used commercially, a steam boiler provides the necessary energy. High pressure steam is expanded through a series of jets or ejectors arranged in series, and is condensed in barometric condensers mounted below the ejectors. Cooling water for condensing is provided through the use of an induced-draft cooling tower. By means of this apparatus a pressure at about 4.6 mm of mercury, corresponding to a final temperature of 32 F, is gradually reached.[9] The system is first purged of air as the pressure falls. When the boiling point of water is reached, vapor from the products is drawn through the ejectors into the barometric condensers. Controls may be either manual or automatic. Cooling is stopped when the desired pulp temperature has been reached.

The second method produces the vacuum by means of mechanical vacuum pumps, preferably of the rotary vane type. With adequate pumps, approximately 8 to 10 min are required to evacuate the air from the system. When pressure is reduced to a point corresponding to a temperature a few degrees above that of the commodity, refrigeration is applied to the vapor condenser. This condenser is sometimes situated in the vacuum line above the chamber and ahead of the pumps, or may be in the vacuum chamber itself. The condenser must contain adequate surface to condense the large amount of vapor removed from the produce in a few minutes. Refrigeration is furnished the condenser either from cold brine or from a direct-expansion system. A very large peak load occurs due to the rapid condensing of so much vapor. Consequently, best results are obtained if the refrigeration plant is equipped with a large brine or ice-making tank having enough stored refrigeration to smooth out the load. A standard 3-tube plant, with capacity to handle 3 cars per hr, will have a peak refrigeration load of at least 50,000 Btu per min, which represents a 250 ton refrigeration load.

Mechanical vacuum coolers have been designed in several sizes. Most installations use cylindrical or rectangular retorts, sized to hold either a half- or a quarter-car of produce. However, several plants have been constructed which are large enough to hold the entire refrigerator car or highway van. The vehicle and its load are subjected to the vacuum, and the load cools in the normal cycle, with the rate of cooling being a function of the vacuum pump capacity and size of the condenser.

A modification of the mechanical vacuum-pump system uses an ice condenser in place of the mechanically refrigerated condenser. This is particularly adapted for use in areas where production is seasonal and full use of the equipment demands portability. The use of an ice condenser also substantially reduces cost of the equipment as compared with mechanical condenser units.

The rate of cooling and the final temperature attained by vacuum cooling are affected largely by the ratio of the surface area of the commodity to its mass and the ease with which the product gives up water from its tissues. Thus, fruits and vegetables vary tremendously in their adaptability to this method of precooling.[13]

Lettuce is ideally adapted to vacuum cooling. The numerous individual leaves provide large surface area and the tissues release moisture readily. In fact it is quite possible to freeze lettuce in a vacuum chamber if pressure and condenser temperatures are not carefully controlled. However, even lettuce does not cool entirely uniformly. The fleshy core, or butt, releases moisture more slowly than the leaves. Temperatures as high as 42 F have been recorded in core tissue when leaf temperatures were down to 33 F.[14] Fig. 6 illustrates the importance of providing ample time for complete cooling after evacuation of the vacuum chamber.

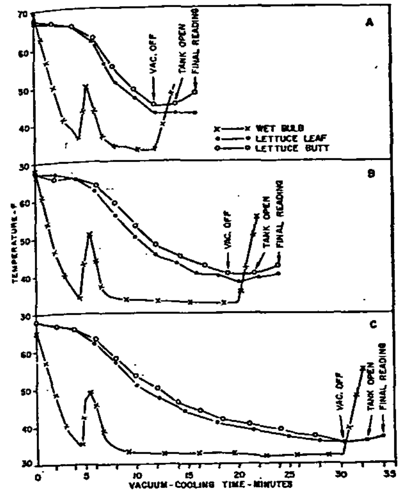

Fig. 6 .... Effect of Cooling Time on Wet-bulb and Lettuce Temperature during Vacuum Cooling[14]

Recent studies with green peas and sweet corn[9,11] have shown that these two products can be satisfactorily cooled by vacuum and that their subsequent market life was the same whether vacuum-cooled or hydrocooled. Unpublished data obtained at the U. S. Horticultural Field Laboratory in Fresno, California indicate that globe artichokes, asparagus, snap beans, broccoli, brussels sprouts, and celery can also be adequately cooled by vacuum, and that subsequent keeping quality is not adversely affected. Misting these products with water before cooling improves cooling and reduces weight loss.

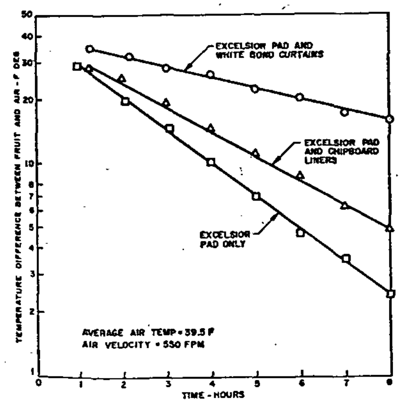

Fig. 7 .... Effect of Packaging Material on Rate of Cooling of Grapes in Standard Display Lugs[16]

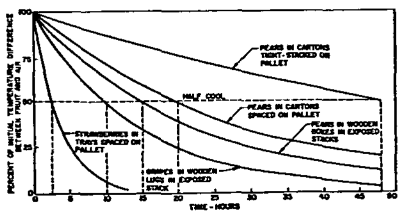

Fig. 8 .... Room Cooling of Fruits in Typical Situations (Average Fruit Pulp Temperatures)[4]

In the same study, little cooling was obtained with cucumbers, cantaloupes, tomatoes, dry onions, and potatoes. This would be expected because of their low surface-to-mass ratio and relatively impervious surface.

EFFECTS OF CONTAINERS AND STACKING PATTERNS

The accessibility of the product to the cooling medium, essential to rapid cooling, may involve access to the unit within the container or to the individual container in a stack.[1,16]

Fig. 7 illustrates the effect of packaging materials (box liners and curtains) on the cooling rate of grapes under constant temperature and air-movement conditions. The marked effect of commodity, container, and stacking pattern in room cooling is shown in Fig. 8. Strawberries in open flats (single layer of cups) with spaces between the rows of trays were half-cooled in 2½ hr, while pears in solid-stacked cartons required about 48 hr for half-cooling at similar temperatures and air velocities. Other types of containers and load patterns were intermediate in cooling rate.

Similarly, studies in the Pacific Northwest have shown that the cooling of carton-packed apples and pears can be substantially increased by spacing rows or stacks in the storage room. Tests in British Columbia demonstrated that spacing apple containers on pallets reduced cooling time by 50 percent as compared with pallet loads stacked solidly.[17] A somewhat similar study in the state of Washington compared cooling rates of pears in wooden boxes with those in cartons, in both solid and spaced stacks.[18] While spacing materially improved cooling in both containers, the difference in favor of spacing was much greater in the carton-packed fruit. In the tight stacks the wooden boxes had an advantage because the bulge in the packed boxes allowed some air flow between the stacks.

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