of the volatiles causing unusual or characteristic flavor of single-strength tangerine juice are removed during vacuum or high-temperature/short-time concentration. The product is smooth and bland without unusual flavor characteristics. Some tangerine concentrates are blended in small quantities with orange juice concentrates to improve color and impart sweetness. United States regulations limit the amount of tangerine juice in orange juice to 10%. In the United States tangerines are grown primarily for the fresh market and only the surplus from that use is available for processing. With rare exceptions, no tangerines are produced in the United States exclusively for processed products.

FROZEN CONCENTRATED ORANGE JUICE

The development of frozen concentrated orange juice is a classic example of a timely product which came about due to a coincidence of developments in food technology, equipment and process engineering, marketing technology and consumer demand. Its first successful production took place in the mid 1940s. A number of techniques for concentrating and dehydrating citrus juices previously had been explored and tested but all had deficiencies of one kind or another. Citrus concentrates which had been produced prior to World War II had unsatisfactory flavor because of heat damage, and loss of volatile constituents. Some were used in Great Britain as dietary supplements and for the armed services of the United States and Britain. Some of those were sterilized with sulphur dioxide or benzoic acid, which contributed to unsatisfactory flavor.

The new product, which was produced in the season of 1945–46, was initiated primarily on the basis of research carried out by workers of the Florida Citrus Commission and the U.S. Department of Agriculture at the USDA Research Laboratory in Winter Haven, Florida. A combination of several technological breakthroughs was mainly responsible for the development of a product with a great potential for successful marketing. During World War II, the engineering designs were developed for two types of evaporators that could be adapted for concentrating heat sensitive products: the low-temperature/high-vacuum and high-temperature/short-time evaporators. The development of the concept of 'cut-back' juice helped to overcome flavor deficiencies due to loss of volatiles. In this concept the original base product was over-concentrated, then fresh juice was added to dilute the concentrate back to the desired level. The fresh cut-back juice restored volatiles for the entire concentrated product. Then researchers found that the product could be frozen and stored at low temperatures for long times with relatively little flavor deterioration

or loss of vitamin C. Those advances were augmented by the widespread distribution of home refrigerators and freezers during the 1940s, and many food and beverage companies began developing low temperature marketing and distribution systems.

Historical Development

On April 19, 1944, L. G. MacDowell, Research Director of the Florida Citrus Commission, outlined a series of experiments that were to be conducted by Commission Research Fellows, E. L. Moore and C. D. Atkins. They were stationed at the Fruit and Vegetable Products Laboratory of the Agricultural Research Service, U.S. Department of Agriculture, with M. K. Veldhuis, In-Charge. Workers in the USDA and the Florida Citrus Commission cooperated to work out the process outlined by MacDowell. This outline described the essential features for concentration of orange juice. In this program, juice was concentrated under vacuum at low temperature, fresh cutback juice was added to the over-concentrated product to bring it back to the desired concentration and restore fresh flavor and aroma, and the final material was packed as a frozen product. Until a few weeks before MacDowell's proposal, the USDA laboratory had no program for development of concentrate, but had equipment that was suitable for preliminary studies. Results of those studies were promising and thereafter much of the effort of the laboratory was directed toward development of the product.

MacDowell, Moore and Atkins were granted U.S. Patent Number 2,543,109 (1948) for the method that was developed. Because the patent was based on cooperative work by State and Federal organizations it was assigned to the U.S. Government, as represented by the Secretary of Agriculture. In 1956, the U.S. Department of Agriculture presented the Winter Haven laboratory with its highest honor, the Distinguished Service Award for the development of frozen concentrated orange juice. The group was listed as L. G. MacDowell, E. L. Moore, C. D. Atkins and E. E. Wiederhold for the Florida Citrus Commission, and M. K. Veldhuis, R. Patrick and A. L. Curl for the USDA. Because the research work was well founded and timely and because of the remarkable coincidence of several technological and marketing developments, frozen concentrated orange juice has been one of the most successful food products ever developed. Its production in Florida has grown steadily from about 852 thousand l in 1946 to over 674 million l in 1975. The story of its spectacular development was reported in many popular magazines and in trade and technical journals.

A schematic of the overall process is shown in Fig. 4.21. There

Evaporators

The citrus juice evaporator is probably the major technological component of the frozen concentrated orange juice industry. The large scale evaporators that are used for delicate-flavored, relatively heat sensitive materials have developed through many stages, and much engineering skill has gone into their design. Their development was facilitated by the technology of World War II which refined high vacuum evaporation techniques for the manufacture of perishable materials, particularly penicillin. During that period the falling film evaporator also was developed and adopted by the juice industry. Evaporators have been important in the development of many fruit and vegetable juices and of other liquid food products.

Early evaporators consisted simply of a centrifugal pump that forced the liquid through a heat exchanger where some of the water was evaporated on each pass. Vapors and liquid were separated in an enlarged chamber, and the vapors passed across a vacuum line, with vacuum provided by a steam jet system. Liquid was continually recycled through the heat exchanger until the desired concentration was reached. The lowest practical operating temperature for those evaporators was about 49°C, and was limited by the temperature of the water available for the barometric condenser. Because of the height of the liquid column maintained in the heat exchanger, the temperature of the liquid increased substantially during the concentration process. The system used about 1.3 kg of steam for each kilogram of water evaporated and, by today's standards, was inefficient. The temperature of the evaporator was ideal for pectinesterase activity, and orange juice had to be heat treated to deactivate pectinesterase before it was fed to the evaporator. The evaporator was operated batch-wise and juice was fed to the unit until a sizable batch of the desired concentration accumulated. The concentrate was then pumped from the unit and a new batch started.

The first commercial low temperature orange juice evaporator designed to take advantage of research carried out at the Winter Haven laboratory was built at Plymouth, Florida, by Vacuum Foods Company. This company later became Minute Maid Corporation, Minute Maid Division of Coca Cola Corporation and now is designated the Foods Division of the Coca Cola Corporation. That evaporator was a falling film type and consisted of a series of vertical stainless steel cylinders about 91.4 cm in diameter arranged so that the juice sprayed against the inside surface of the top of the cylinders, flowed down the inside surfaces and was warmed by a water

jacket. Vapors were drawn upward into steam jets which discharged into barometric condensers. The jackets of the large tubes were heated with warm water from the barometric condenser. Because the tubes were large, vapors did not impede the downward flow of juice, and continuous vaporization of the water kept the temperature of the juice relatively low (about 10°C). This unit was placed in operation on April 1, 1946, with about half its output consigned to frozen concentrated orange juice. Concentrate of 42° Brix was filled into 177 ml (6-oz) cans and packed under the Snow Crop label. In the first year of operation, this evaporator provided all of the 852,000 l of concentrated orange juice produced during the 1945-46 citrus season. The following year a second similar evaporator was installed and the evaporation temperature was raised to about 21°C (Roy 1970). These evaporators effectively demonstrated the principle of falling film evaporators and indicated that concentrates could be prepared at low evaporation temperatures.

After the quality of the product from low temperature evaporation had been demonstrated at the Minute Maid Plant in Plymouth, several falling film evaporators, manufactured by the Skinner Company, were redesigned for low temperature evaporation. They previously had been used at Citrus Concentrates Inc., Dunedin, Florida, for hot-pack concentrates. The evaporators were arranged in a shell and tube system, so that vapors ascended while the juice descended on the inside surfaces. Vapor was drawn off by a steam booster and passed through a barometric condenser. At least a dozen of these evaporators were built and used for 5-10 years. They processed most of the frozen concentrated orange juice packed during the first 10 years of manufacture.

Majonnier Brothers built their first falling film, refrigerant heat pump cycle evaporator for citrus juice at Florida Citrus Canners Cooperative, Lake Wales, Florida. In this system, hot gases from a refrigerant furnished heat to falling film heat exchangers, and liquid refrigerant in adjacent heat exchangers condensed the water vapors. Both the vapors and the film of juice traveled in the same direction. Thus, the rate of travel of the film and the efficiency of heat exchange were increased. Three stages were connected by a common vacuum system and the product traveled from one to the other in a continuous cycle. This unit, called the Majonnier Lo-Temp evaporator, was heralded as a marked advance and began operating in 1947.

During the late 1940s, a number of companies entered the evaporator design and construction field. These included Buflo-Vak Division of Blaw-Knox, Kelly, and Gulf Machinery Company. Double