has been partially concentrated. Tubular and plate type pasteurizers are in common use. In a few plants, treating the partially concentrated juice the heat is supplied by steam injection, the cut-back juice is not heated. The efficiency of the heat treatment is judged by observing samples stored in elevated temperatures such as 140 F. In one case samples are stored at this temperature for 48 hr, others have suggested a week at 40 F or 24 hr at 80 F. The quality product still requires storage at 0 F.

Concentration

This phase of the process is discussed in detail in the later section Concentration Methods.

Packing, Storing, and Distribution

The concentrate is packed in cans of several different sizes and with several different enamels on conventional canning equipment. The sealed cans then pass through a blast freezer, typically attaining a can temperature of −30 F in approximately 45 min. Once the concentrate is canned and frozen, it is desirable to keep at storage temperature at 0 F or below. Current transit practice includes the use of a sealed recording thermometer with each load of frozen concentrate. This reliable indication of possible over-temperatures has succeeded in reducing transportation and storage losses to a minimum.

Quality Control

Controls on the quality of frozen fruit juice concentrates must be exercised throughout the process, and by this careful control the final quality is assured. United States standards for the various concentrates have been established. In analyzing the final concentrate, the reconstituted product is tested for Brix value, Brix acid ratio, peel oil content, ascorbic acid content and appearance. In the leading orange juice concentrating plants the testing is done by resident government representatives and at present only the highest grade produce (U. S. Grade A) is marketed. The importance of rejecting bad fruit before extraction cannot be over-emphasized, for these may introduce factors which chemical washing and bactericides cannot quell. The processing equipment must permit sanitary operation and to this end it is desirable to provide for minimum juice holdup. Normally the evaporators are cleaned every 7 days, and everything else every 12 hours. Finally, the company control must be all embracing and rigid and the standards set by an individual company must be higher than those set by government standards, especially those dealing with sanitation and cleanliness.

In addition to routine chemical and physical analyses made on incoming fruit, and freshly extract juice, a bacteriological test is made to measure total organism count, mold count and a specific test for the presence of the organism *E. coli*. While in itself this organism is innocuous, it indicates the presence of material and organisms of fecal origin. Should this organism be present, more exhaustive tests are made to determine whether the juice is to be rejected or used. After concentration, a reconstituted sample of juice is again tested bacteriologically as well as chemically, physically and by taste. If the total count of a final sample is over 1,000,000 per cu cm of reconstituted juice, the product is not distributed. Actually, the count in operation runs much lower (of the order of several thousand per cubic centimeter), and are taken as a measure of a plant cleanliness. The concentration process is based on asepsis rather than anti-sepsis.

CONCENTRATION METHODS

The major methods for the production of fruit juice concentrates are: (1) freezing followed by mechanical separation of concentrate and ice, (2) low temperature vacuum drying to powder, and (3) low temperature vacuum evaporation.

Freezing and Mechanical Separation

Gore and others developed a method for concentrating juices by freezing which, in principle, is identical to the method of concentrating *applejack*. These juices are a mixture of constituents and therefore do not have a sharp freezing point. As the temperature is lowered, pure water crystallizes progressively, leaving a liquid residue with a progressively higher concentration of fruit juice solids. Mechanical separation yields ice and concentrate.

The method used by Gore was to freeze 50 gal drums of juice in large baths. The drum was then put into a warm bath to free the cake which was then crushed. The crushed juice concentrate-ice mixture was then centrifuged, separating the liquid concentrate from the ice which was discarded.

This method gave a good quality product, but losses in soluble solids were relatively high, the process was cumbersome due to the handling requirements, and low temperatures were needed. Because of these factors and the inadequacy of facilities for distributing high quality frozen products, this early attempt to make high quality juice concentrate was not a financial success.

A modified process has been developed for concentration by freezing the juice to a slush in a scraped surface refrigerated heat exchanger. The ice, which contains some sugars and flavors, is separated from the ester-rich liquor in a centrifuge. The ice is then mixed with pulp and concentrated by conventional low temperature evaporation. This product is mixed with the liquor to form the final concentrate product. Although this process is slightly more expensive than concentration by low temperature evaporation above, a better flavored product is claimed, since a smaller percentage of the volatiles is lost in the vacuum processing.

Vacuum Drying to Powder

One manufacturer has successfully produced a dried orange juice powder using a USDA process. Frozen orange juice, concentrated to 58 percent solids, is thawed as required and mixed with dioxide fumes. This feed is introduced into a vacuum belt drier at 20 F. The dried product is mixed with essence granules and packaged with a desiccant (calcium lime) in a controlled humidity room. The essence granules consist of a high quality cold pressed citrus oil absorbed in sorbitol. The solid sorbitol, a partially hydrogenated dextrose, acts as a hermetic barrier, preventing oxidation rancidification of the absorbed oil.

In addition to the obvious savings in storage and distribution costs, a considerable savings in capital equipment with modest reductions in operating cost are noticed in comparing this process with methods of producing frozen concentrates.

Vacuum Evaporation

At the present time, nearly all of the frozen fruit juice concentrates are produced by low temperature evaporation.

In current practice, filtered juice is fed into the vacuum system. First of all, dissolved gases flash off. Then the juice is fed to the top of a vertical heat exchanger (evaporator). As it passes down the heat exchanger, either in film-type or flooded-type flow, it is heated and water evaporates at a temperature corresponding to the pressure in the evaporator. For orange juice this temperature is usually between 50 and 70 F at pressures of around 10–30 mm Hg abs. The growth of engineering knowhow through wartime activities made large scale commercial high vacuum operation possible.

The vapor generated is removed either by condensing it at

the pressure of the system and pumping it out as a liquid or by pumping it out of the system and compressing it to a higher pressure, following which it may be condensed or cycled back to heat the evaporator.

The earliest installations employed a series of wetted wall evaporators all operating at essentially the same pressure (single effect). Heat was supplied by hot water heated by a boiler and the condenser cooling water carrying the heat of condensation was run down the drain.

The desirability of reclaiming the heat of condensation for use in further evaporation was soon recognized and the principle of the heat pump was put into effect. Further economies were realized by using multiple effect systems in which successive evaporators are maintained at lower and lower pressures, and consequently lower temperatures, thereby permitting vapor from the first evaporator (first effect) to vaporize the liquid in the second evaporator (second effect) and the vapor from the second to vaporize water from the third evaporator (third effect) and so on. The implications of multiple effect evaporation are: (1) since theoretically a pound of steam evaporates a pound of water, and since this in turn evaporates another pound of water, etc., the total amount of water evaporated per pound of steam (or equivalent energy) supplied to the first effect is N, where N is the number of effects; and (2) the available temperature differential across any effect is $1/N$ times the temperature difference for a single-effect system, and therefore the area of the heat transfer surface must be adjusted accordingly.

At the present time the heat pump principle is in general use in conjunction with single-, double-, and triple-effect systems. The basic principle of the heat pump is that the temperature level of a heat carrying medium is raised by doing mechanical work on the medium such as the adiabatic compression of gases and vapors. Heat pump systems in use for juice concentration either make use of refrigeration systems in which a centrifugal or reciprocating compressor raises the heat level in the refrigerant, or thermo-compressor systems in which booster type steam ejectors raise the heat level of water vapor. However it is done, a net amount of energy equivalent to the work done is added to the system and must be dissipated to maintain a steady state.

Examples of the use of the heat pump follow, together with their relative advantages and disadvantages.

Direct Refrigerant Contact

Fig. 1 shows a schematic system of concentration in which hot refrigerant gas is used to supply the heat for the evaporation of juice. Conversely the juice evaporator acts as the refrigerant condenser (high side). The water vapor is condensed by the evaporating liquid refrigerant in a shell-and-tube condenser. Conversely the water vapor heats the refrigerant (low side). The refrigerant is returned to the suction of the compressor unit and the cycle is repeated. The evaporator, for simplicity, is shown as a single effect with means for recirculating the juice. Variations may employ multiple effects, or parallel single effects. Vapor and concentrate are separated, usually by an arrangement of cyclones and baffles. The concentrate is pumped out of the system and fed to the blending, chilling, canning, and freezing processes. The vapor is condensed and pumped out of the condenser to waste. The pressure in the system can be maintained by a relatively small steam ejector or a mechanical vacuum pump.

Advantages of this system are:

1. Very little cooling water or steam are required. This is of basic importance in most citrus producing areas. Steam is required only to maintain pressure and water to remove heat of compression.

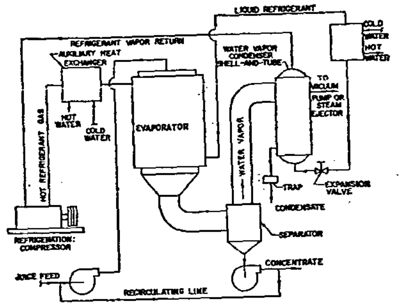

Fig. 1 .... System of Concentration Using Heat Pump Principle (Direct Refrigerant Contact).

2. Equipment associated with cooling water and steam is minimized, saving space and expense.
3. Since the refrigerant vapor directly heats the juice and cools the vapor, a minimum temperature differential from refrigerant to juice can be employed. For a given juice temperature the temperature of the hot refrigerant can be at a minimum and that of the cold refrigerant in the condenser can be at a maximum. This requires minimum energy input to the compressor.

Disadvantages of this system are:

1. Unitary refrigeration cannot be used. The refrigeration systems, controls, and instrumentation must be specifically designed for the particular installation.
2. Refrigerant hold-up is relatively high.
3. Evaporating equipment must be constructed to withstand refrigerant pressures. Any leak in the evaporators can cause contamination of the juice with refrigerant.
4. Refrigerant lines are relatively long.

Indirect Refrigerant Contact

Fig. 2 shows a schematic system of concentration which, though similar to that shown in Fig. 1, differs in the following ways: (1) the juice is heated by circulated hot water, which in turn is heated by the hot refrigerant gases (high side); and (2) the vapor from the juice is condensed by direct contact with cold water in a water jet condenser, the water having been

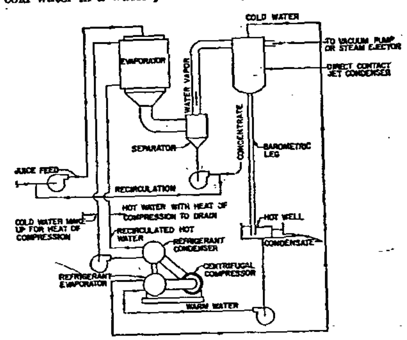

Fig. 2 .... System of Concentration Using Heat Pump Principle (Indirect Refrigerant Contact)