INDUSTRIAL PROCESSING OF CITRUS FRUIT

FOOD INDUSTRY STUDIES No. 2

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FOREWORD

The present monograph is one of a series of studies designed for the use of the food-processing industries of developing countries. The approach used and the criteria that have been followed are based on the concept that, while capital for investment may not be readily available, skilled labour in short supply, and present markets for the products limited or even non-existent, processes and techniques must be adopted that will produce goods that can compete, in quality, price, and reliability of supply, with those of countries whose industrialization has begun earlier. No country, and especially no developing country, can afford to waste its resources by building industries whose products are too high in price and/or too low in quality to have acceptability in the world market.

The objective of UNIDO in publishing this series of studies in the food-processing industry is therefore to provide information to the developing countries that will help them to gain good technical insights into selected areas of food-processing and to avoid obsolescent procedures and processes. It is hoped that this series of studies will provide reliable and practical information for governmental authorities and for potential private and institutional investors.

The present monograph was prepared by Professor Zeki Berk of the Technion-Israel Institute of Technology, Haifa, Israel (Visiting Associate Professor of Food Engineering, Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.) in the capacity of Consultant to UNIDO.

CONTENTS

ECONOMIC BACKGROUND

Citrus fruits and their industrial derivatives have been long recognized as commodities of established importance in international trade. No other single class of fresh fruit or its processed juice products enjoys the popularity and international sales volume of the citrus fruits. The scale of this trade can be seen in table 1 and table 2.

The geographical regions that can sustain the commercial culture of citrus fruit are limited. Both the need for much water and the high susceptibility of most citrus fruit to frost damage restrict citrus-growing areas. However, improvement of irrigation methods has permitted some expansion of citriculture into regions that were formerly too arid for this purpose.

The development of highly palatable concentrated frozen juices explains the spectacular growth of the citrus industry and trade in the USA. However, the impact of this important development outside of North America has been very slight thus far. The countries of Europe that do not produce citrus fruits are the principal markets for fresh fruit and their processed products. Citrus-based "soft" beverages and single-strength canned or bottled juices are still the principal most widely sold industrial citrus products in these countries.

All parts of the fruit of the commercially important citrus varieties (oranges, grape-fruit, lemons and limes) can be utilized industrially and yield salable products. The diversity of the products that can be obtained from citrus fruit is shown in the diagram in figure 1. However, the market for some of these products is quite small or already saturated, the production of orange-peel oil, citrus pectins and flavonoids exceeds the actual demand. In some cases, such as the production of citric acid, the development of competitive sources has eliminated or reduced considerably the prospects of profitable operation.

The purpose of the present report is to provide basic information on the processes of industrial utilization of citrus fruit, on the available equipment for these purposes and on the characteristics and properties of the principal products and by-products. In an Annex, some economic considerations are illustrated by means of a feasibility study for a small plant operating under hypothetical local conditions.

The last two decades have seen a phenomenal development of the citrus industry, both in plant size and in the diversity and sophistication of production technology. Several promising techniques are now under investigation, and some of these have reached the stage of pilot-plant development. Since the present publication is intended for those seeking information useful for the evaluation of feasibility in a new and presumably small-scale operation, emphasis has been placed on the more conventional technology, but recent developments in the field are discussed briefly.

The author wishes to acknowledge his indebtedness to the Israeli citrus industry, in which he has received most of his experience. Thanks are also due to the Minute Maid Company of the United States of America for valuable information and an instructive visit to its plants in Florida. To the Pladoth Company (food equipment and stainless steel work, Ein Harod, Israel), Sharnoa Ltd. (mechanical equipment, Petach Tikwa, Israel), and to the Industries Development Corporation (engineering, design, economics studies, Haifa, Israel) gratitude is due for valuable assistance on questions related to engineering and economics.

Table 1. Export of citrus juices from principal producing countries (1963)
(In thousands of tons)

Product	Italy	Spain	Israel	Algeria	Morocco	USA
Orange, single-strength			20	3.5	4.0	24
Orange, concentrate	13	8.0	3.5	–	0.5	18
Grape-fruit			3.5	0.5	2.5	23
Lemon			2.5			–
Comminuted	–		6.5	–	–	–
Blended	–	–			–	11

Source: The Commonwealth Economic Committee, *Fruit, a Review*, H. M. S. O., London, 1965.

Table 2. Imports of citrus juices into the United Kingdom
(In thousands of tons)

Product	Average 1951-55	1960	1962	1963
Orange, natural	6.5	9.0	8.0	10.5
Grape-fruit, natural		1.5	1.5	2.0
Orange, sweetened	7.5	9.5	9.5	9.0
Grape-fruit, sweetened		9.5	10.5	9.5
Orange, concentrate	9.0	8.5	5.0	5.0
Grape-fruit, concentrate		1.0	0.5	0.5
Others, natural		15.0	13.5	10.0
Others, concentrate		3.0	3.5	2.5

Source: The Commonwealth Economic Committee, *Fruit, a Review*, H. M. S. O., London.

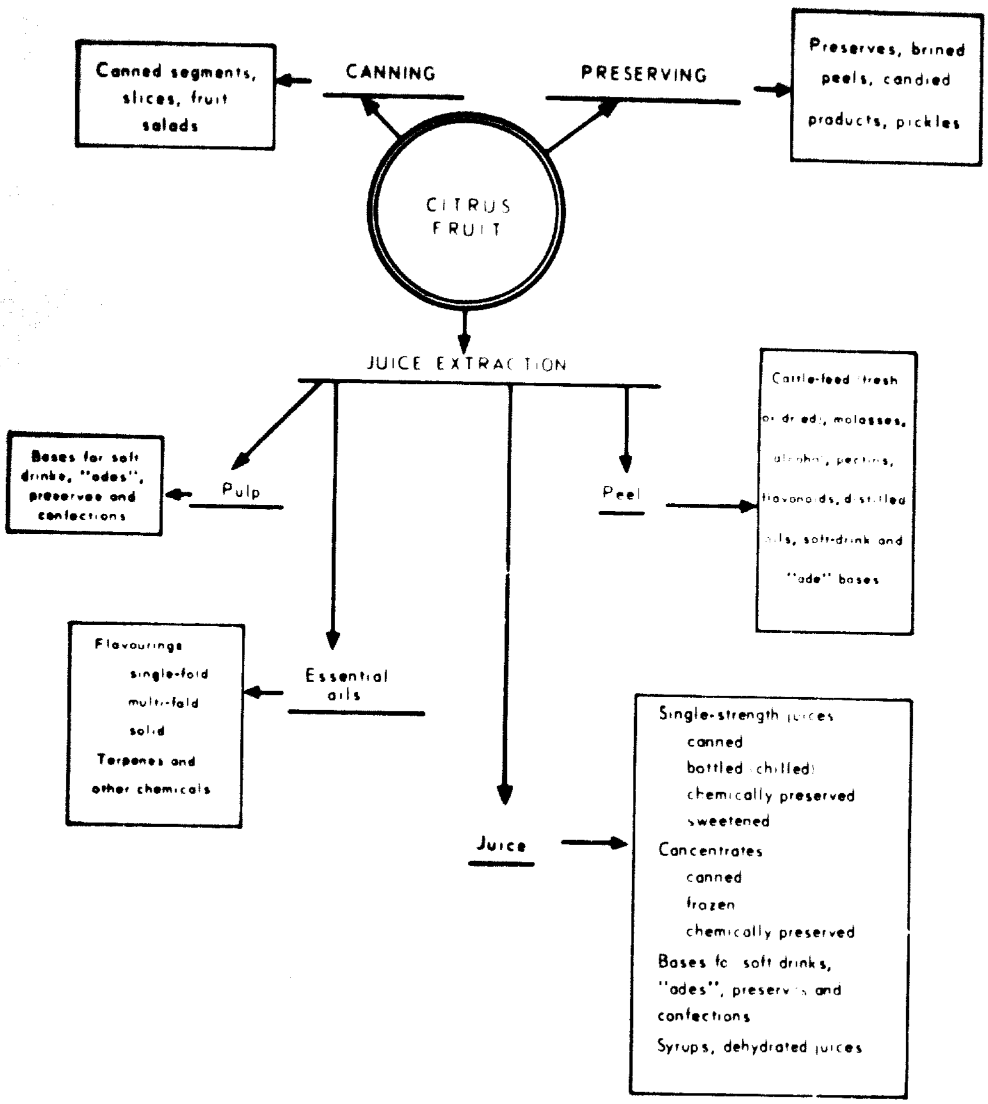

Figure 1. Most common products of the citrus processing industry

Chapter Two

PRODUCTION TRENDS

Extensive statistical data are compiled and published yearly by various governmental and international agencies (see the Selected References). These data indicate a remarkable increase in world production of citrus fruit, particularly in some of the developing countries (table 3).

Table 3. Citrus fruit: production, 1953-55 and 1957-61 averages, and 1962 to 1965[a]

(In thousands of tons)

	1953-55 average	1957-61 average	1962	1963	1964 prelim-inary	1965 estimate
Oranges and tangerines						
Winter season						
United States of America[b]	4,509	4,473	3,643	3,178	4,377	4,838
Mediterranean region	3,704	4,521	4,835	5,942	5,850	6,324
Elsewhere	1,860	2,504	3,440	3,294	3,675	3,698
TOTAL	10,073	11,498	11,918	12,414	13,902	14,860
from						
Developed countries	7,765	8,753	8,140	8,658	10,112	11,044
Developing countries	2,308	2,745	3,778	3,756	3,790	3,816
Summer season	3,998	4,517	5,114	5,172	4,884	-
from						
Developed countries	1,182	1,097	1,123	1,202	1,166	-
Developing countries	2,816	3,420	3,991	3,970	3,718	-
WORLD TOTAL[c]	14,071	16,015	17,032	17,586	18,786	-

[a] Seasons beginning in year shown. Totals include the northern hemisphere harvests starting in the year shown and the southern hemisphere harvests in the following year.

[b] Excluding California Valencia orange production which is included in the summer season total.

[c] Excluding the USSR and China (Mainland).

Source: FAO Commodity Review, 1966.

Table 3. (continued)

	1953-55 average	1957-61 average	1962	1963	1964 prelim-inary	1965 estimate
Lemons and limes						
Winter season						
United States of America	532	601	463	673	524	613
Italy	311	389	359	488	562	520
Others	635	786	1,189	1,113	1,162	1,187
TOTAL	1,478	1,776	2,011	2,274	2,258	2,320
Summer season	251	300	341	329	315	
WORLD TOTAL[c]	1,729	2,076	2,352	2,603	2,573	
from						
Developed countries	994	1,270	1,154	1,462	1,395	–
Developing countries	735	806	1,198	1,141	1,178	–
Grape-fruit						
Winter season						
United States of America	1,613	1,500	1,225	1,249	1,506	1,705
Israel	60	69	98	137	159	175
Others	133	161	178	189	207	215
TOTAL	1,806	1,730	1,501	1,575	1,872	2,095
Summer season	53	123	171	187	197	
WORLD TOTAL[c]	1,859	1,853	1,672	1,762	2,069	–
from						
Developed countries	1,710	1,622	1,402	1,480	1,767	–
Developing countries	149	231	270	282	302	–
TOTAL CITRUS FRUIT PRODUCTION	17,659	19,994	21,056	21,951	23,428	–

This trend has already affected marketing patterns. In 1966 and 1967, the European markets for fresh fruit were so competitive that very often break-even prices could not be obtained. In the near future when the new plantations, in both the established citrus-producing areas and among the newer ones come into production, the imbalance between supply and demand for fresh fruit will become even more serious. According to a forecast by the Food and Agriculture Organization of the United Nations (FAO),[1] even at reduced prices the market will be unable to absorb all of the additional fruit that will become available. On the other hand, demand for ready-to-consume convenience foods is increasing following changes in living standards and dietary habits. Processed citrus products will undoubtedly benefit from this trend.

A surplus of raw materials on one hand and an increased demand for products derived from them on the other most probably will bring about a phenomenal growth of the citrus-processing industry in the near future in both developed and developing countries. At the same time, a substantial increase in governmental and industrial support for research directed towards the development of new processes and products may be expected.

[1] See item No. 39 in the list of Selected References.

RAW MATERIALS

Sources of fruit for processing

The principal source of fruit for industrial processing is the culls from packing-houses. Culls are sound, healthy fruit that cannot meet the requirements of the fresh fruit market because of non-standard, irregular shape and superficial peel blemishes. Because of the higher returns to the grower, it is usual to sell as much of the crop as possible as fresh fruit, but there is always some of the crop that cannot be. This proportion varies according to factors such as the variety of the fruit, climatic conditions during the growing season, geographic regions, and age of the trees. With the market for fresh fruit becoming ever more sophisticated and demanding, the proportion of culls has increased all over the world. The fruit-growers have thus come to consider the citrus-processing industry as an important factor, necessary for the absorption of 30 to 40 per cent of the crop, despite the relatively low prices paid by the industry for culls.

Obviously, this arrangement has some severe drawbacks. The quantity of culls available to the industry fluctuates within wide limits and often unexpectedly according to climatic conditions and marketing policy. The occurence of frost damage in one citrus-producing country may create such a shortage of fresh fruit in the world market that the standards are lowered, much fewer culls are sorted out and the citrus-processing industry everywhere suffers from unavailability of raw material.

Furthermore, the varieties of citrus fruit most suitable for eating fresh are not necessarily the best for processing. For example, while most navel oranges are excellent fresh fruit, their usefulness in industry is limited by a degree of bitterness that develops in their pasteurized juices.

An alternative method of supplying the industry with raw material is to utilize the entire crop for processing, as is done in the USA in Florida. The huge market created by the advent of successful frozen concentrates and the favourable price commanded by these products, together with the convenience of receiving a steady supply of well-specified raw material, permit the industry to offer the growers a price considerably higher than that paid for culls. On the other hand, the costs of growing, picking and transporting the fruit may be substantially lowered.

Characteristics of fruit varieties

The individual species of citrus fruit and the use of each one in the industry have been summarized by Braverman.[1] The present discussion emphasizes the effect of varietal characteristics on the suitability of citrus fruit for commercial processing.

(a) *Shape and size.* Some processing equipment must be selected or adjusted according to the size and shape of distribution of the fruit. The operations most sensitive to this factor are washing (brushes), sizing and especially juice extraction.

(b) *Hardness and thickness of the peel.* Varieties with thin but sufficiently hard peels are, of course, preferable. Soft-skinned fruits such as tangerines require special care in conveying and juice extraction.

(c) *Juice yields.* Unless the fruit is processed primarily for its oil, the yield of juice is extremely important. Many varieties that are excellent for eating fresh, such as Jaffa oranges, may have less extractable juice than other varieties less suitable for eating fresh.

(d) *Colour.* This factor is especially important in the case of oranges. The market demands orange juice with a deep "orange" colour. This requirement is further emphasized in the case of concentrates and bases, where the colour should be quite pronounced even after extensive dilution. Some varieties, although excellent in taste and aroma, yield a juice of pale colour, and vice versa. A good balance of flavour and colour may be obtained by blending such juices. Thus, tangerines may be used to enhance the colour of other juices despite their weak flavour when processed.

(e) *Composition.* A good balance of sweetness and tartness is essential. This factor puts rather strict limitations on the sugar/acidity (°Brix pH) ratio.[2] Since vitamin C is the most important nutritive factor in citrus juice, a high ascorbic acid content is very desirable. The absence of excessive bitterness, whether originally present in the fruit or induced by the treatment, is of course essential.

(f) *Length of the season.* It is evident that citrus tree varieties that can provide mature fruit over a long period of the year are extremely desirable. A combination of early, mid-season and late-bearing varieties is the best way to lengthen the fruit-production season.

Maturity

The definition of fruit maturity for industrial purposes differs somewhat from that used by the fresh-fruit market. Generally, oranges reach "processing maturity" some time after they are sufficiently mature for eating fresh. Artificial ripening is effective in colouring the peel. While this is important for the fresh-fruit market, it does not render the fruit more suitable for processing.

As the fruit matures, its juice content increases. However, juiciness cannot be used as the only criterion for maturity, because juiciness is also affected by many other factors and changes observably only very early in the growing season.

Immature grape-fruit are excessively bitter and acid. The bitterness is caused by high concentrations of naringin, a bitter crystalline glycoside. Recently, de-bittering

[1]See entry No. 1 in the list of Selected References.

[2]The Brix scale is a hydrometric scale for sugar solutions so graduated that its readings in degrees Brix (°Brix) at a specified temperature represent the percentage by weight of sugar in a solution.

processes have been proposed whereby excess naringin would be decomposed by means of the enzyme naringinase. Excess citric acid can be removed by electrodialysis. Although both processes have been described in the recent literature, neither is used commercially at present.

With oranges, maturity is more difficult to define than with grape-fruit. Early in the growing season an orange of a given variety may be reasonably juicy and sweet, but may develop a distinctly bitter taste in its juice upon processing. Furthermore, the colour of the juice is generally pale and a green nuance can be detected, especially in concentrates.

In the case of grape-fruit for the manufacture of canned segments, neither juiciness, sugar content nor acidity can be taken as indications of maturity. The texture of the segment is more important. Both immature and over-ripe fruit yield less firm segments than does mature fruit. The use of shear-presses for the determination of optimal maturity has been investigated, but no conclusive data are available as of yet.

The most useful criterion for maturity seems to be the ratio of total soluble solids (degrees Brix) to acidity (expressed as citric acid). However, the optimum sugar/acidity ratio suitable for the manufacture of single-strength juice may be different from that required to obtain a good frozen concentrate. Furthermore, the optimum ratio depends also upon the variety of fruit being processed. Unfortunately, the experience of the processor is still the best guide for determining the suitability of fruit for processing.

RECEIVING OPERATIONS

Transportation and unloading

Although the production of canned single-strength citrus fruit juice is discussed in detail elsewhere in the present report, it is so typical of citrus processing that a flow-sheet for a plant for this purpose is presented in figure 2 and will be referred to several times

Citrus fruit for industrial use is usually transported in bulk. Damage to the fruit is not a matter of concern provided that the distances of transportation are short, the fruit is not over-ripe or bruised and the depth of the load is not too great. The carriers may vary from giant trailers with capacities as great as 25 tons to horse-drawn carts that carry only a few hundred kilograms.

In well-organized, large-scale operations it is possible to achieve a great degree of automation of the receiving operations by standardizing carrier dimensions and construction. A reasonable receiving procedure for medium-scale plants consists of an unloading pit with slanted walls and a roller conveyor at its bottom. The fruit is discharged into the pit by dump-trucks, or if such are not available, by lifting the front wheels of an ordinary truck by means of a hydraulic jack and platform, as shown in figure 2.

The capacity of the fruit-receiving line must be sufficiently large to avoid unnecessary delay of carriers, to cope with peak supply situations and to permit future expansion. If no other considerations are important, an unloading capacity equal to three to four times the processing capacity of the plant will be adequate.

Before being admitted into the storage bins the fruit is inspected, and damaged material is discarded. In Florida, where fruit is bought on the basis of tons of soluble juice solids rather than tons of fruit, it is necessary to draw a representative sample from the main stream of incoming fruit. This sample is weighed and pressed under specified conditions. The yield of juice and soluble solids content are determined. This practice is recommended even when the quality of the fruit does not affect payment. It is very desirable to keep a record of the condition and composition of the fruit and its variation throughout the season. Such data are essential for planning production schedules.

In some plants, the fruit is given a first washing with chlorinated water before it enters the storage bins. The purpose of this operation is to improve the sanitary condition of conveying equipment and bins. In warm damp climates this practice is not recommended, since excess moisture on the fruit tends to produce rapid spoilage during storage, especially when the fruit is held for more than 12 hours.

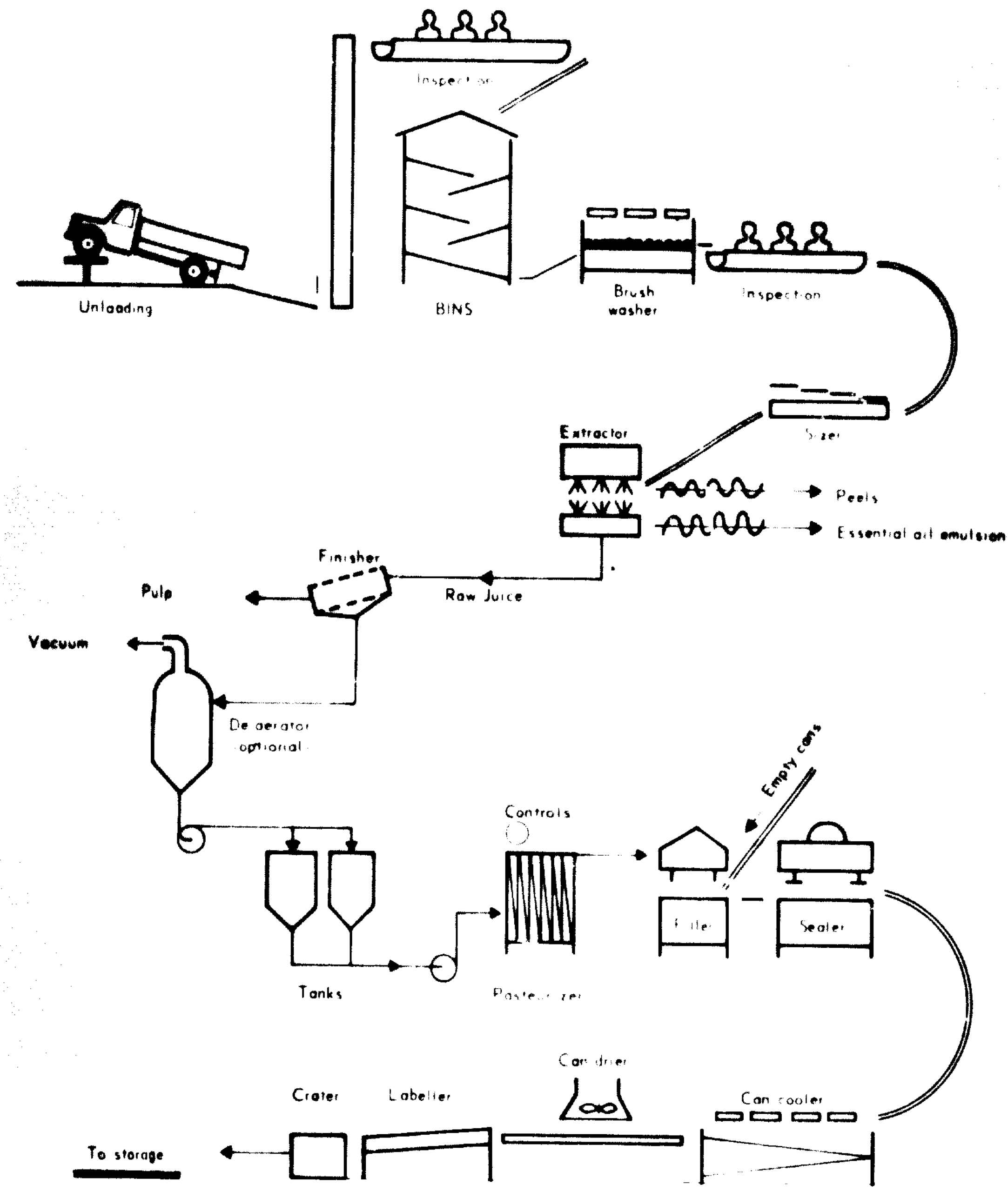

Figure 2. Flowsheet of single strength canned juice production

Fruit varieties such as tangerines, which have thin and soft skins, cannot withstand bulk transportation and storage in bins. Such fruit should be delivered in field boxes and fed directly to the final washing line.

Storage of fruit

Storage between receiving and processing is necessary to ensure continuity of plant operation despite fluctuations in fruit delivery. The length of such storage will depend to a large extent on the nature of the delivery procedure and the production schedule. Thus, when the plant management has some control over picking and delivery, the intermediate storage period may be shortened considerably. Also, processing a single variety of fruit uninterruptedly during a portion of the season reduces the requirements for storage time and volume. Under conditions of good co-ordination between fruit supply and processing, rapid turnover of the inventory in storage may be secured, and the storage time can be as short as 15 to 20 hours. In the absence of such ideal conditions, storage periods of several days are frequent.

The design of storage bins also depends on the anticipated rate of turnover. Whenever need for long-period storage is expected, bin construction should permit extensive natural ventilation to prevent spoilage and overheating. Metal bins with sheet-steel baffles and wire-mesh walls are suitable. Wooden or concrete bins may be used for short-term storage. The bins should be provided with inclined baffles to prevent damage due to the weight of the fruit bearing on the lower levels and to lessen the extent of bruising during the fall of the fruit into the bin. Such an arrangement is shown in figure 2.

Washing and sorting

The importance of effective washing of the fruit before it is pressed cannot be over-emphasized. While modern juice extractors have been successful in minimizing contact between the juice and the exterior of the fruit, the danger of contamination of several designs and materials are available corresponding to the size, shape and peel is still present. Good washing of the fruit also reduces the formation of slime on the conveyors and facilitates the sanitary upkeep of the extractors.

Thorough washing of most citrus fruit can be achieved by a series of operations as follows:

Soaking. The fruit is immersed in water containing wetting agents or detergents. Several such products, approved by the public health authorities, are presently in use. The fruit should remain in the soaking tank until all dirt is sufficiently softened; this may require one minute.

Brushing. A short elevator transfers the fruit from the tank to a series of revolving brushes, where it is literally scrubbed under a shower of water (see figure 2). Brushes of several designs and materials are available corresponding to the size, shape and peel toughness of the fruit. If the fruit delivered to the plant is relatively clean, the soaking operation may be omitted, and detergent may be sprayed on the fruit during brushing.

Rinsing. The fruit may be rinsed on the brushes or on a roller conveyor following them. Fan-shaped jets of water at a pressure of 4 to 6 atmospheres should be used. It is advantageous to rinse with water containing approximately 20 parts per million of free chlorine. Once-used rinse-water may be admitted into the soaking tank, thus permitting frequent change of the soak-water with good economy.

At this point, it is necessary to inspect the fruit and discard all rotten, mouldy and broken fruit, as well as any extraneous material and fruit of unwanted variety or unusual size. This operation is generally carried out after washing, since handling clean fruit is somewhat easier for the sorters. However, if the proportion of defective fruit is too large, it may be advantageous to remove such fruit before washing in order to avoid extensive contamination of the soak water and brushes. Sorting is done by hand while the fruit passes slowly on a conveyor. A roller conveyor that rotates the fruit as it advances is most convenient. Good lighting is essential. Such inspection is shown in the plant flow-sheet presented in figure 2.

Chapter Five

EXTRACTION OF JUICE

Juice is by far the most valuable citrus fruit product. The process of pressing or extraction has a definite effect on the amount of juice obtained as well as on its quality and may therefore be regarded as the most critical operation in commercial citrus processing.

The juice is, strictly speaking, only the liquid contained in the thin-walled, club-shaped "juice sacs" of the endocarp. In practice, however, commercial citrus juice also contains varying amounts of pulp (broken walls of juice sacs and of segments, debris from albedo, and the like, albedo liquids and essential oils from the flavedo. One of the most important features of modern juice-extraction equipment is its adjustability, so that the extent to which such components are included in the juice may be controlled. Very often processors tend to take advantage of this feature in the direction of over-pressing for higher yields. This practice results in a definite impairment of the organoleptic properties and stability of the juice.

At present, only fully automatic juice extractors are in commercial use. Three such machines are described and discussed below.

The Faglith type of extractor was developed in Israel from earlier rotary models. It is now manufactured and sold in Italy.[1] The machine comprises two pairs of revolving drums, on the surfaces of each of which hemispherical hollows have been embossed. The two drums of each pair rotate in opposite directions. The fruit is caught in the spherical space between the corresponding hollows of the two upper drums and is forced against a sharp blade, which cuts it in two. The halves are transferred to the hollows of the lower pair. In the course of one revolution, the extractor head, which carries hollow plungers of a special shape, is pressed against the halved fruit. The juice flows through the plungers to a collecting manifold. The degree of pressing may be adjusted by varying the clearance between the drum-hollow surfaces and the plungers at the end of their stroke. Since no provision is made in this device for the simultaneous collection of peel oil, the fruit must first be subjected to rasping under a jet of water. The process of peel-oil recovery by this method is described elsewhere. The Faglith extractor and others of its same type are relatively simple, sturdy machines, the maintenance, adjustment and servicing of which are easy. Their capacity is 3 to 4 tons per hour according to the size of the fruit.

The Brown extractor[2] also begins by halving the fruit. The halves are held by means of inverted cups, while revolving rosette-shaped reamers empty them. In the

[1]Produced by Bertuzzi S. A., Milan, Italy (Citropress).

[2]Produced by Brown International Corporation, Covina, Calif., USA.

recent model, the cups and reamers are situated on revolving tables and meet each other at an angle. Since the operation is based on rotary reaming and not on pressure, inclusion of coarse pulp and peel liquids may be minimized to a large extent. The machine is rather complicated and requires special skill for servicing.

The FMC (Food Machinery Corporation) Inline juice extractor[3] is a recent development, based on the "whole-fruit extraction" principle formerly featured in the FMC turn-table machines. The extractor consists of three or five pairs of fingered cups installed in a straight line. At the start of the cycle the cups are kept apart and a fruit is introduced into the lower cup. The upper cup is then lowered. The fingers interlock and form a closed space. As the distance between the cups decreases, the fruit is pressed against the sharp edge of a tube situated at the base of the lower one. A circular portion of the peel is cut and the contents of the fruit are forced, through the hole thus formed, into the tube. This tube has a perforated wall through which the juice is pressed out, flowing into a receiver and then to a collecting manifold. The rag, seeds and circular piece of cut peel remain within the tube and are discharged through a special orifice. At the same time the peel is removed by the fingers of the upper cup.

The principal advantages of the FMC extractors are the elimination of the preliminary halving step and efficient prevention of contact between the juice and the outer surface of the peel. Essential oils are released from the peel by the pressure and washed down by a shower of water. Thus, the three main commercial components of citrus fruit juice, peel and essential oils are recovered in a single operation as three separate streams. If desired, the rag portion (orifice discharge) may be collected as a fourth stream.

FMC extractors are fed from a belt conveyor tilted towards the machine. The fruit rolls into the channels of a feeding table, whence it is transferred to the cups, either by a channelled elevator or by a rotating level (positive feeding). In order to utilize the full capacity of the extractor, it is important that each of the cups at every stroke be filled. This can be achieved by admitting on the tilted belt-feeder an amount of fruit by 10 to 15 per cent in excess of the full capacity of the extracting line. Thus all of the machines will be filled and excess fruit will be collected at the end of the line and recirculated.

The theoretical capacity of an FMC extractor, calculated from the number of cups and frequency of strokes per minute, is 3 to 4 tons per hour. In a small factory, under present conditions of feeding and size distribution, the average hourly capacity per extractor is more likely to be 2.5 tons for oranges and 3.5 tons for grape-fruit.

All three types of automatic extractors described require pre-sizing of the fruit; the feed is adjusted according to fruit size. Each size group is conveyed to a different battery of extractors equipped with cups or grooves corresponding to the size of the fruit. A good knowledge of the expected size distribution of the fruit is essential in designing the juice-extraction line and conveying systems. Several methods of size classification exist. The most commonly used device is a belt-and-roller sizer, where the fruit travels on a tilted belt. A roller is installed near the outer (lower) edge of the

[3]Produced by FMC Corporation, Santa Clara, Calif., USA.

belt, at an adjustable height from it. Fruit with a diameter smaller than the belt-to-roller clearance will fall, while larger fruit will continue to travel to the next section where the clearance is larger. Such a sizer is included in the flow-sheet of a citrus-juice canning plant presented in figure 2.

SINGLE-STRENGTH JUICES

Only single-strength citrus juices produced primarily for direct consumption are considered here. Reconstituted juices, which are made by dilution of concentrates, and citrus-based drinks are discussed separately.

Characteristic properties

Obviously, an ideal fruit juice is one that retains all of the characteristics of the freshly pressed material. Although this ideal is impossible to achieve at this time, present technological knowledge permits a close approach to it. Let us first consider the deteriorative changes that may take place in the product during processing and storage.

Microbial deterioration. Raw juice contains many micro-organisms of different kinds, such as bacteria, moulds and yeasts. Early investigations reported the presence of as many as one million living cells per cubic centimeter of juice. The first apparent microbial deterioration, which may occur quite rapidly at room temperature, is alcoholic fermentation caused by yeasts. Surface growth of moulds and lactic fermentation may also take place. The more acid juices of grape-fruit and lemons are more resistant to most types of microbial attack than is orange juice. Nevertheless, all raw citrus juices should be regarded as highly perishable.

The approach most commonly adopted for the suppression of spoilage is thermal inactivation of the micro-organisms. The juice is heated and held at high temperature for a given length of time. The temperatures and times used in practice aim at the destruction of yeasts, non-sporeforming bacteria, moulds and the like. The more-resistant organisms are not destroyed, but the acid medium prevents their subsequent development. Such a partial thermal sterilization is known as pasteurization.

The number of living organisms that remains in the juice after pasteurization is directly proportional to the number of cells that were initially present. It is therefore important to avoid extensive build-up of the microflora before pasteurization. Effective washing of the fruit, reduction of holding time of raw juice and strict adherence to the principles of sanitary plant design and operation are essential.

Colloidal changes. Fresh citrus juice is a homogeneous cloudy suspension of tiny solid particles in a sweet-sour serum. These particles are not finely disintegrated pieces of pulp or peel but probably a distinct anatomical portion of the fruit, with a particular chemical composition. This cloudy suspension is stabilized by a system in which the pectic substances play an important role. If this system is preserved, the "cloud" will remain in suspension for a long time, but if it is destroyed, flocculation of the particles and their separation in the form of unsightly agglomerates will take place, and the bulk of the juice will undergo clarification. This breakdown is a major cause of quality loss.

One of the principal factors in the destruction of the stabilizing system is the enzymatic breakdown of pectic substances. Pectin-splitting enzymes are naturally present in the juice. Their concentration in the pulp is much higher than in the clear serum. Their action starts immediately after juice extraction. Fortunately, heat treatment is also a good method for the inactivation of enzymes. Pasteurization thus has the double function of stabilizing the juice both microbially and enzymatically. Non-enzymatic breakdown of the colloidal structure is also possible. Our present knowledge of this type of deterioration is very limited.

Changes in flavour. The distinctive flavour of fresh citrus juice results from the taste imparted by the sugars and acids and from the odour for which a multitude of volatile substances is responsible. Changes in taste may result from the formation of new substances during processing and storage, and changes in odour occur as a result of loss and/or chemical alteration of the volatile substances, as well as through the formation of new odorous materials. Generally, all of these changes are undesirable.

The development of bitterness in the juice of California navel oranges or immature oranges of many other varieties has been described in chapter three, "Raw Materials". Because of this limitation, such juices can be used only for blending purposes. Another taste deterioration commonly encountered is the development of a "cooked" taste. The exact nature of this phenomenon is not known. Most of the cooked flavour is imparted to the taste of juice during heat-treatment, but the impairment continues in the package if the storage temperature is high. A mild cooked taste may be described as a "flat flavour", while more advanced deteriorations are referred to as "hot-oil taste" and finally, as "burnt, caramelized".

No heat-treatment process is now available that completely avoids taste deterioration. However, such deterioration can be kept to a minimum. De-aeration, absence of excess essential oils, short-term processing and rapid cooling after pasteurization are some of the precautions to be taken to avoid it. Orange juice seems to be more susceptible to cooked taste than do grape-fruit and lemon juices. Also, the juice from early fruit is somewhat more sensitive than that from later fruit. Under reasonable conditions of manufacture and storage, odour deterioration is seldom a problem in single-strength juices. This type of quality loss is therefore discussed in connexion with concentrates, where the problem is more serious.

Changes in colour. The most important change in juice colour is attributable to a process known as "non-enzymatic browning". A series of reactions involving primarily the amino acids and ascorbic acid of the juice results in the formation of dark pigments. This is a relatively slow change, enhanced by high storage temperature and high acidity. It is especially serious in lemon juice and bottled (not canned) grape-fruit and orange juices. It is advisable to store single-strength, pasteurized lemon juice in a refrigerated warehouse at a temperature of 3°C to 5°C.

The manufacturing process

Since the earlier stages of the production of canned single-strength citrus juices have already been used to illustrate citrus processing in general, let us refer to figure 2, at the point where the raw juice leaves the extractor.

Screening. The raw juice coming from any automatic juice extractor contains too much coarse pulp for direct packaging. The first operation is therefore one of screening or finishing. Two methods of screening are in use: free screening and pressure finishing (as shown in figure 2). In free screening the pulp is not subjected to pressure. Therefore, only "free" juice is recovered, but the pulp is quite wet. Free screening prevents extraction of a large quantity of disintegrated pulp into the juice. The importance of this in the case of concentrated juices is explained in chapter seven. Free screening may be accomplished either in a perforated drum rotating slowly or on vibrating screens. Vibrating-screen machines are more compact than the former, but they appear to incorporate large quantities of air into the juice. However, a de-aerator may be introduced into the production line at this point (figure 2). Pressure finishing is done by means of screw presses. With this process, the yield of juice is higher and the pulp discharged is drier. Obviously, the juice has more "body", but this is not objectionable in single-strength juices.

The screened juices are collected in covered stainless steel tanks equipped with stirrers. These vessels may serve for blending, addition of sugar (in the case of sweetened juices) or simply as balance reservoirs for the subsequent operations. A sufficient number of them should be provided to permit both continuous operation of the line and frequent washing of the tanks. The individual tanks should be sufficiently small to avoid in-process holding of raw juice for long periods.

Pumping of juices. Very often, the layout of the plant may require the use of pumps for the transfer of juices from one point to another. Sanitary centrifugal pumps are generally used. Care must be taken to exclude air. This can be done by maintaining a sizable positive head of pressure at the suction end of the pumps (elevated tanks; liberal pipe diameter; short, straight and unrestricted piping between tank and pump).

Pasteurization. Plate pasteurizers, similar to those used in the dairy industry, are now customary in fruit-juice processing. These consist of embossed metal plates pressed together to form alternating channels for the flow of juice and the heating (or cooling) medium (see figure 2). The heating medium may be steam or pressurized hot water, the latter permitting easier control. A heat treatment of 30 seconds at 87°C is sufficient for orange juice, but slightly milder treatment is adequate for grape-fruit and lemon juices. The temperature is automatically controlled and recorded. A "flow diversion valve" system is useful whereby any portion of juice that does not reach the desired temperature in one "pass" is diverted from the product line and recirculated.

The most commonly used sequence of juice processing is heat-fill-cool, as shown in figure 2. The juice coming from the pasteurizer is filled into the container while still hot. The high temperature of the juice is sufficient to pasteurize the inside surface of the container and its lid. In-process holding time is not controlled, since it is assumed that the duration of retention of the juice in the filler and in the can prior to cooling is ample. There is a danger that unnecessarily long holding at high temperature and undue slowness of the in-package cooling may produce an objectionable cooked taste.

An alternative method uses the sequence heat-cool-fill. The pasteurizer is provided with a holding section in which the juice is retained for exactly the desired holding time. The juice is then rapidly cooled or even chilled in a heat-exchanger (usually an additional section of the same plate heat-exchanger). Since the cooled juice cannot now pasteurize the containers, it becomes necessary to sterilize the empty packages and lids before filling and to carry out the filling operation under aseptic conditions. Aseptic filling for juices has been advocated, but it appears to be seldom done commercially, presumably for reasons of cost. The heat-cool-fill sequence without aseptic filling is being used for chilled juices or for "soft" beverages packaged in plastic or in lined cardboard, with preservatives added.

Can filling and closing. The selection of can-filling and -closing equipment depends on the capacity of the production line. An inexpensive filling device consists of a short conveyor travelling under a series of open nozzles. The conveyor carries empty cans, while juice flows freely from the nozzles. The rate of flow and conveyor speed are regulated to ensure complete filling. This method, which is quite commonly used for low-speed operations (20 to 30 cans per minute) cannot be recommended. Over- and under-filling are unavoidable, and sanitary conditions are difficult to maintain. The overflow must be collected, cooled and re-pasteurized. An excessive amount of air is introduced into the can in the form of foam.

Automatic juice fillers of sanitary design are available for a wide range of capacities. The relative merits of the different types are a matter of controversy. However, rotary piston fillers seem to be preferable. There are no particular requirements for the can seamer. However, machines that hold the can still while the seaming head rotates are preferable, since they reduce spillage. The seamer can be synchronized with the filling machine, thus making the filling and closing steps one automatic operation. The empty cans must be steam-cleaned and inverted before filling, in accordance with established sanitary canning practice.

Cooling. The cans and their contents should be rapidly cooled to room temperature. This is most conveniently done by means of spin-coolers. The cans are rotated around their axes on an inclined belt conveyor. At the same time, cold water is sprayed on in the form of cone-shaped jets. A No. 2 can[1] of orange juice can be cooled from 80°C to 30°C in 2 to 3 minutes. Since a partial vacuum is formed inside the cans during cooling, suction of water through the seams of the can may occur. To avoid re-contamination of the juice, the cooling water should be absolutely clean and preferably chlorinated.

In order to avoid rust, the cans must be dried before being cased. The cooling operation is often interrupted when the cans are at 40°C to 45°C to accelerate natural drying of the outer surface. However, a process whereby the cooling is carried out as far as possible and the cans are dried by independent means such as blowers or brushes is preferable. Cans that are crated at 45°C will retain a high temperature for

[1]A No. 2 can has a net liquid capacity of 1 US pint, 2 fluid ounces (approximate net weight of 1 lb. 4 oz.).

a long time, and a marked cooked taste and increased risk of spoilage and internal corrosion will result.

Packaging in glass. Because of the supposed sales-appeal superiority of bottles over cans, there is some demand for bottled single-strength juices in Europe. The process of bottling is similar to canning. However, special machines are required for filling and capping. Crown caps or pilfer-proof screw-caps are used. The bottles should be thoroughly washed and pre-heated to avoid breakage. Cooling should also be slow for the same reason. In-bottle pasteurization, commonly used for apple juice, beer and wine cannot be applied to citrus juice, since a cooked taste would be induced. Despite all precautions, precipitation of pulp is unavoidable, and the appearance of the product in transparent glass is not always attractive. Dark glass, which also offers some protection from light, is therefore preferred.

Chilled juice. Fresh, non-pasteurized juices of orange and grape-fruit may have a shelf-life of several days if kept at 0°C at all times. However, since such conditions cannot be assumed in retail marketing, the use of non-pasteurized chilled juice is limited to institutional consumption in the vicinity of the plant. In a method more commonly used, the juice is cooled and chilled in bulk after pasteurization in the usual way. It is filled, cold, into lined cardboard containers or bottles and shipped under refrigeration. Sanitary requirements are particularly stringent. Considering the similarity between this product and pasteurized milk from the viewpoint of marketing problems and shelf-life, it is interesting to note that dairy companies in the USA are most active in the distribution and sometimes the production of chilled citrus juices. It should be noted that the production and marketing of chilled juices in other countries is still very limited.

Chapter Seven

CITRUS-JUICE CONCENTRATES

General considerations

Citrus juices naturally contain 86-90 per cent water, and their bulk can be reduced greatly by the removal of most of it. The advantages of concentration from the points of view of packaging, transportation and storage cost are evident. Furthermore, the stability of the product is also improved in several aspects. Three types of concentrated citrus juices are available in the trade: frozen, pasteurized (hot-pack) and chemically preserved. A block diagram of these three types of citrus concentrate production is presented in figure 3.

Frozen concentrates are sold primarily for direct consumer use. Upon dilution with the proper amount of water they yield a beverage comparable to or better than natural canned juice. Usually they are sold at a concentration of 4 : 1 (i.e., the bulk of natural juice has been reduced to one fourth by concentration). These concentrates must be kept frozen at all times. Storage and distribution temperatures below -18°C are essential for good quality. This factor renders the production and marketing of frozen concentrates impracticable in many countries. Indeed, at the present time large-scale retail marketing of frozen citrus concentrates is limited to the USA.

Canned (hot-pack) concentrates generally do not reach the consumer directly but are used in the manufacture of soft beverages or reconstituted juices. The juice obtained by dilution of these concentrates is comparable or inferior to canned single-strength juice. However, palatable reconstituted juices may be obtained from good quality hot-pack concentrates when the flavour is "corrected" with essences. Pasteurized concentrates are marketed at concentration ratios in the order of 6 : 1.

Chemically preserved concentrates are used for the manufacture of popular bottled soft drinks and confectionery. Their concentration is also at the 6 : 1 range. They are generally marketed in wooden barrels with a chemical preservative (usually sulphur dioxide).

Characteristics of citrus-juice concentrates

Ideally, a good citrus concentrate is a product that, upon dilution with an appropriate amount of water, yields a beverage identical to the juice from which it was made. However, changes that occur during processing and storage prevent attainment of this ideal. These changes are summarized below.

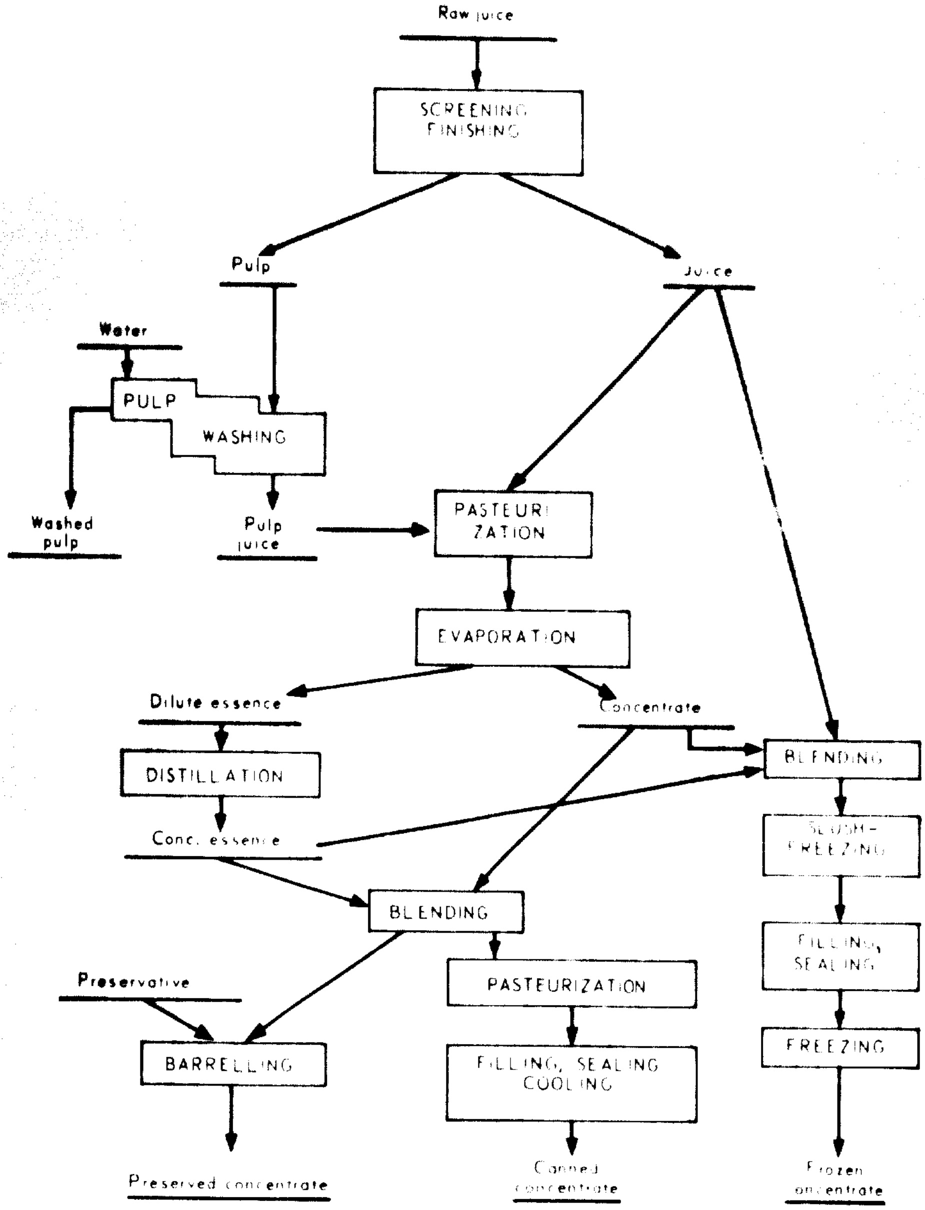

Figure 3. *Diagram of citrus fruit concentrate production (with essence recovery)*

Changes in flavour. The conventional method of concentration is evaporation. When a juice is concentrated by evaporation, water is not the only substance removed; most of the volatile essences that give taste and fragrance are also lost. These substances may, however, be recovered from the vapours and returned to the juice. Alternatively, some fresh juice may be added to the concentrate to replace some of the lost flavour. These two methods, known respectively as "essence recovery" and "cut-back", will be discussed later.

Since evaporation is a thermal process, it may also alter the flavour by cooking. Cooked taste may be minimized by reducing the temperature of evaporation (high-vacuum evaporation) or by decreasing the retention time of the juice in the hot regions of the evaporator.

Discolouration. As may be expected, change in colour ("browning") is a much greater problem with concentrates than with juices. Indeed, the higher the concentration, the more rapid is the rate of discolouration. In frozen concentrates, the low storage temperature prevents any perceptible degree of browning. In pasteurized concentrates, however, the problem is very serious. If kept at room temperature, a 4:1 lemon concentrate would become chocolate brown in a few weeks. The only way known to date to keep browning under control is refrigerated storage. Since grape-fruit and lemon concentrates have a greater tendency to undergo browning than orange juice, they are generally prepared at lower concentrations.

In chemically preserved concentrates, the spoilage-preventing additive most commonly used, sulphur dioxide, is also an effective inhibitor of browning. If the concentration of free sulphur dioxide is kept sufficiently high at all times, excessive browning can be prevented.

Colloidal changes. The viscosity of citrus concentrates increases tremendously with concentration. A typical orange concentrate of 60°Brix may have a viscosity of 5000 to 10,000 centipoise, while the viscosity of single-strength juice is about 2 centipoise. The viscosity depends strongly on the quantity of pulp material present in the juice.

Sometimes, a high-solids concentrate (e.g., 65°Brix) may revert from a highly viscous but still fluid material to a hard, firm gel. Obviously, such a product has lost all of its commercial value. Several mechanisms may cause this gelatinization. For example, the high concentration of sugars and acids may modify the colloidal state of the pectin to form a gel, just as it happens in jellies and jams. In some cases, this type of gelatinization may be prevented by the admixture of a small amount of sodium citrate, which acts as a buffer and prevents excessive drop of the pH with increasing concentration. In most cases, however, gelatinization follows the action of pectolytic enzymes. Consequently, to prevent it, it is essential to inactivate the enzymes in the freshly pressed juice.

Manufacturing processes

Preparation of the juice for concentration. To reduce concentrate viscosity, the amount of pulp suspended in it must be reduced. The first operation after juice extraction is therefore screening. Free screening through perforations 0.8 to 1.0 mm in diameter is necessary for concentration beyond 60°Brix. Screw presses with screens of 0.4 to 0.6 mm diameter and moderate pressure may be used for frozen concentrates. The degree of screening necessary to prevent excessive viscosity and gelatinization also depends upon the variety of fruit used.

The discharged pulp still contains a considerable amount of juice. The current practice is to recover most of the soluble solids of the pulp by a leaching process. The pulp is washed with water in several steps connected in counter-current fashion. The soluble solids are recovered in the form of a 6-7 per cent solution, which is mixed with the screened juice. The leached pulp is discarded, used for cattle feed (fresh or dried) or comminuted as a "clouding" agent for beverages (see figure 3).

It is now necessary to stop the action of the pectolytic enzymes by subjecting the screened juice to a heat treatment similar to that already described for single-strength juices. The use of screw presses and pulp-washing tends to increase the concentration of pectins and pectolytic enzymes. Whenever these high-yield techniques are used, the heat treatment must be somewhat more rigorous.

The evaporator may be connected directly to the heat-treatment unit so that the hot juice is immediately flashed into the vacuum chamber. Alternatively, the juice may be cooled and stored in a balance tank, from which it is fed into the evaporator. The former method represents better steam economy, but its applicability depends on the construction and operation principle of the evaporator.

Evaporation. Modern citrus-juice evaporation equipment is based on either of the two possible approaches to the problem of minimizing heat damage: low temperature or short contact time.

As with any other liquid, the boiling point of citrus juice may be lowered by reducing the pressure. Many industrial citrus-juice concentrators operate with very low pressures, corresponding to boiling points (based on water) of 18°C or below, thus obviously eliminating the danger of cooking. However, the method has serious limitations. Operation at high vacuum entails increased initial cost of equipment as well as operating expenses. Ordinary cooling water is not sufficiently cold for the condensation of the vapours at such pressures, so chilled water, refrigerated brine or direct-expansion refrigerant systems must be used. The viscosity of the concentrate is much higher at low temperature. As a result, heat transfer is bound to be slow, and retention time is long. There seems to be no appreciable advantage from the viewpoint of retention of volatile substances.

In recent years, emphasis has been put on shorter contact time rather than on low temperature. Pressure is reduced only sufficiently to obtain boiling at 45-55°C. However, the concentrate remains in contact with the heating surface for only a few seconds. Rapid evaporation is secured by an improved rate of heat transfer. Most of the modern evaporators are termed "film evaporators", since the concentrate is heated in the form of a thin film moving over the heat-transfer surface. There are several different techniques for forming and moving this film. Some of the more commonly used methods are described below.

In *plate evaporators* the juice is passed through a plate heat-exchanger similar to the plate flash-pasteurizer for single-strength juices described on page 54 but with a larger gap between the plates. Considerable evaporation already takes place in the heat-exchanger. The vapours formed move at high velocity towards the exit, thereby causing rapid movement of the liquid film in the same direction. Further evaporation takes place when the mixture of vapour and liquid expands into a separation chamber connected to a vacuum pump or ejector system through an efficient condenser. If the degree of concentration achieved in a single pass is not sufficient, the concentrate may be recirculated or sent to a second evaporator of the same type (multi-stage operation). An important feature of the plate evaporator is its ease of cleaning. The plates can be quickly opened, and all parts in contact with the food are thus readily made accessible for inspection and cleaning. Evaporators of this type, supplied by the Aluminium Plant and Vessel Company Ltd., in the United Kingdom, are now in use in several citrus-processing plants.

Falling- and/or climbing-film evaporators make use of the same principle of utilizing high-velocity vapours for moving the liquid film. The heat-transfer surfaces are vertical cylindrical or conical tubes. In the case of climbing-film evaporators, the liquid is introduced at the lower end of the tubes, and the film moves upward solely by the propelling action of the vapours. However, since viscosity increases with concentration, this movement slows down and scorching may occur. Consequently, climbing-film evaporators should not be used to achieve high concentration ratios. With falling-film evaporators, the movement of the film is secured by gravity as well as by vapour propulsion. Higher concentration ratios can be achieved with falling-film systems or with evaporators using a climbing-film section as a first step and a falling-film section for finishing. Several versions of this principle may be found in large-scale evaporators especially adapted for the citrus industry. Typical examples are the Taste[1] and Buflovac[2] evaporators extensively used in Florida and California, and the Pladoth[3] evaporator made in Israel. The first two of these are huge machines with capacities as high as 100 tons per hour, the third is supplied for capacity ranges of 1 to 10 tons.[4]

Swept-surface evaporators make use of mechanical devices to move the film. The heat-exchanger consists of a vertical or horizontal tube within which an agitator rotates at high speed. The blades of the agitator "sweep" the liquid film over the heating surface. This type of evaporator has limited ability to cope with materials that contain large amounts of coarse pulp unless they are specially designed for this purpose. Swept-surface evaporators are typified by the Turbofilm machines.[5]

The *rotating-surface evaporator* is a more recent development. The heat-transfer surface is an inverted cone that rapidly rotates about its axis. Steam is applied to one side of the cone while juice flows very rapidly in a thin film on the other surface. Retention time is extremely short, and remarkably high concentration ratios can be obtained in a single pass. This machine is known as the Centri-Therm.[6] Several units are presently in use in citrus plants. This evaporator is much more compact than most other machines of comparable capacity.

In all evaporation processes, steam economy is a matter of considerable economic importance. There are several methods of increasing the amount of water removed per ton of steam used, but they cannot be described here. Since all of these methods represent an increase in capital investment, their economic merits should be analysed in close relation to the conditions that prevail in any place where such an installation is planned. However, most evaporators can be equipped with some kind of steam-saving system.

Alternative methods of concentration. The disadvantages of evaporation, such as losses of volatile substances, heat damage, cost of equipment and steam, have led to extensive investigations of alternative methods of water removal.

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[1]Produced by Gulf Machinery Co., Clearwater, Fla., USA.

[2]Produced by Buflovac Equipment Division, Blaw-Knox Co., Buffalo, N. Y., USA.

[3]Produced by Pladoth Co., Ein Harod, Israel.

[4]The capacity of evaporators is rated in terms of tons of water evaporated per unit of time.

[5]These machines were introduced by Luwa AG, Zurich, Switzerland, but similar machines are now produced in the Federal Republic of Germany and in the United States of America.

[6]Produced by Alfa-Laval AB, Lund, Sweden. See entry No. 16 in the list of Selected References.

One of the most-studied processes in this field is termed freeze-concentration or freeze-drying. When a juice is cooled below its freezing point, its water separates as ice crystals, and the concentration of the liquid increases. If the ice is removed as it forms, a concentrate is obtained. Obviously, heat damage is prevented, the volatiles are retained (at least, theoretically) and the energy balance appears to be economically favourable. Several processes, differing mainly in the method of freezing and separating the ice from the concentrate, have been proposed. None has yet found appreciable commercial application for citrus-juice concentrates. One packer company that put a certain method of freeze-concentration into large-scale operation has now discontinued its use.

Membrane processes such as osmosis, reverse osmosis and vapour permeation are still at the stage of laboratory investigation. It is still too early to predict the outcome of such developments in terms of future applications to citrus-juice concentration.

Hot-pack concentrates. The concentrate is withdrawn from the evaporator, cooled and collected in balance tanks, where its composition is checked and corrected. Blending and admixture of recovered essence or essential oils, whenever practised, take place at this stage. The finished product is pumped through a plate pasteurizer where it is rapidly heated to 76°C-78°C. Sanitized cans (commonly No.10[7] or larger) are filled, sealed and cooled as quickly as possible.

Citrus juice is normally pasteurized before evaporation. Since the final concentrate must be pasteurized, one may question the need for the first heat-treatment. Indeed, the first pasteurization may be omitted if the temperature in the evaporator is low or the retention time is short. However, in small-scale operations a double pasteurization is preferable for safety and better flexibility.

Chemically preserved concentrates. The material is cooled immediately after evaporation, standardized and filled into wooden barrels, which must be in good condition and freshly coated with paraffin wax. Sulphur dioxide (2000 to 3000 parts per million) is added directly to the barrels. Other preservatives, such as sodium benzoate (1000 to 2000 parts per million) may also be used if permitted. If so, steel barrels lined with a suitable plastic may also be used. However, since sodium benzoate has no retarding effect on browning, the product must be kept in cold storage.

Frozen concentrates. The good quality of frozen concentrates is in large part due to the practice of "cutting back" (see page 23). A concentrate with a soluble solids level of approximately 60°Brix is prepared in the usual way. Fresh, single-strength juice is then added to a final concentration of 42°Brix. This fresh-juice fraction improves the taste considerably. Further improvement is possible through the admixture of peel oil (within the limits of the specifications) and recovered essence. Blending of concentrates from fruit of different varieties and maturity stages is also common practice.

The juice used for cut-back is usually not pasteurized. Under proper conditions of operation the quantities of enzymes and microorganisms introduced by the

[7] A No. 10 can has a net liquid capacity of 3 US quarts (approximate net weight of 6 lb. 10 oz.).

cut-back portion is not sufficiently large to cause deterioration of the frozen product. If, however, pulp or pulpy juice is used in the cut-back portion, their stabilization by heat is necessary.

Concentrate, cut-back juice, oil and essences are blended in agitated tanks, due care being taken to avoid inclusion of air. Blending in an atmosphere of nitrogen is preferable. The mixture is now cooled until partially frozen. This is generally done in swept-surface coolers such as the Votator machine.[8] The resulting slush is packed, and freezing is completed by a blast of cold air (−40°C) and the product is stored at −18°C or below. Frozen concentrates may be packed in small cans for direct consumer use or in plastic-lined metal barrels for institutional or industrial use or for cut-back. Recently, retail-size cans with laminated cardboard walls have been used with success.

[8]Produced by the Girdler Co. Division of Chemotron Corporation, USA.

Chapter Eight

CITRUS-JUICE BASES FOR SOFT DRINKS

Bases for industrial use

Pure, natural juices have some serious marketing limitations; for example, they are relatively expensive and do not possess the thirst-quenching power of more watery drinks. On the other hand, citrus flavours (traditionally orange and lemon, now also grape-fruit and lime) are established favourites in the field of carbonated and non-carbonated soft drinks. In may cases, this flavour is imparted by essential oils or imitation essences. However, the public seems to prefer cloudy beverages with a more fruity character. These contain varying amounts of citrus components such as juice, concentrate, pulp and zest. They are generally supplied to the bottler in the form of ready-to-use "bases" that are tailored to his needs. These bases are complex, concentrated mixtures to which only water, carbon dioxide, sugar or other sweeteners need be added to obtain the final beverage. They are developed through careful experimentation, generally with the co-operation of the soft-drink bottler. A general survey of the technology of citrus-base manufacture follows.

The raw materials that make up these bases are juices and their concentrates, pulp, peel, essential oils and natural essences. Food acids, stabilizers, certified colours or colour extracts obtained from citrus, chemical preservatives may be added if necessary.

The pulp and peel constituents must be ground to a very fine paste in order to impart to the beverage the desired uniform cloudiness and prevent precipitation. This is done in a series of size-reduction operations, the last of which is invariably comminution in colloid mills. The pulp or peel particles may be subjected to a short steam-cooking operation, using conventional fruit pre-heaters. Cooking increases the output of the mills, but the flavour of the product is somewhat impaired. It is possible to use the different ingredients immediately for the manufacture of base or to store them until needed. Their preservation during storage may be secured by freezing, pasteurization or addition of chemical preservatives according to their final use.

The different components are blended in tanks with agitators. Essential oils are first emulsified in a small amount of concentrate, juice or sugar syrup, using emulsifiers and stabilizers such as brominated essential oils. Ultrasonic homogenizers are very effective in this pre-mixing operation.

It is important to avoid as much as possible the inclusion of air in the processes of comminution and mixing, since high viscosity of the material renders de-aeration difficult. De-aeration is carried out by spraying the mixture into a vacuum chamber

(Pfaudler de-aerator[1]) or by spreading it in the form of a thin film on rotating conical surfaces and applying a vacuum (Fryma de-aerator[2]). Intimate mixing of all ingredients and a certain degree of further size reduction may be achieved by means of high-pressure homogenizers adapted from similar machines used in the dairy industry. The methods of preservation of citrus bases are similar to those used with concentrates for industrial use.

"Ade" bases

"Ade" bases are concentrated products that contain a considerable amount of sugar. They are intended for direct consumer use. When mixed with the proper amount of water, they yield a lemonade, orangeade, limeade or the like; hence their name. By way of illustration, an excellent orangeade base may be made by mixing single-strength orange juice with dry sugar in sufficient amount to give a final soluble-solids concentration of 55-65°Brix (i.e., approximately one part (by weight) juice to one part sugar). In practice, however, concentrates are used rather than juices. The cloud, colour and flavour are intensified as in the case of industrial bases. In the USA, "ade" bases are generally sold in small cans as frozen products. Their concentration is low (40-50°Brix). Elsewhere, citrus "syrups" or "squashes" are more popular. These are sold in bottles or plastic containers in a concentration of about 60°Brix.

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[1]Produced by the Pfaudler and Co. Division of Ritter Pfaudler Corporation, USA.

[2]Produced by Fryma, Rheinfelden, Switzerland.

CANNED CITRUS FRUIT

Grape-fruit segments are the best known and most universally accepted canned citrus fruit product. Mandarin sections, produced mainly in East Asia, are used primarily for decoration. Some seedless varieties of sweet oranges are also packed in limited quantities. The manufacturing processes vary somewhat with the variety of fruit. Grape-fruit products are discussed here to illustrate the basic operations in this field.

Canned grape-fruit segments

Basically, canned grape-fruit consists of segments freed of albedo, seeds and membrane, packed in a solution of sugar and pasteurized in the can. The segments should be firm, unbroken and uniform. The preparation of a quality product requires considerable experience, skill and very rigorous quality control.

The fruit used for this product must be of uniform medium size, ripe but firm and free of blemishes. Culls are obviously not acceptable.

The first operation is removal of the peel. This is generally done by hand. The fruit is first scalded in nearly boiling water for a short time. The heat causes some expansion of the air occluded in the spongy albedo. The peel can now be easily removed. Several machines have been proposed for the mechanization of the peeling operation. In one of them, the scalded fruit is placed on the cups of the machine which cuts and pulls down the peel, much as the manual action. Another machine takes unscalded fruit and cuts the peel peripherally in a mechanism that acts similarly to the peeling of apples. Hand peeling, however, seems to be more generally practised.

The removal of membranes is a delicate process. Two basic methods for this are in general use. In the first, frequently used in the USA, whole peeled fruit are placed in wire baskets and subjected to a bath of hot lye. Pieces of albedo and the dorsal portion of the membranes are removed by this treatment. The fruit is now rinsed thoroughly with water and transported to the "sectionizing table". Here the segments are separated from the inner membranes by hand, using a spatula of special shape.

The second method is more commonly practised in other countries. The workers who remove the peel also break the fruit down to individual segments; these are placed in perforated stainless steel trays, which are conveyed through a series of three baths, as follows: *(a)* a hot caustic bath (approximately 1.5 per cent sodium hydroxide at 90°C, 10 to 20 seconds exposure), *(b)* gentle but abundant fresh-water showers to remove excess lye, and *(c)* a bath of dilute citric acid solution to neutralize any of the caustic which may have remained on the segments. This treatment removes the membranes almost completely. Any sections of membrane that still remain on the segments may be easily removed by hand.

The segments are now ready for canning. They are carefully placed in the cans and hot syrup is added. The concentration of syrup is regulated according to the desired final Brix value and the sugar content of the fruit itself. The "drained weight" (i.e., the weight of segments remaining on a sieve when the syrup is drained off) is an important factor considered by most quality standards. It is necessary to take several steps in order to meet the requirements in this respect. Many processors subject each of the cans (with the segments, before addition of syrup) to a weight check and adjustment. It must be remembered that the drained weight of the product after a few days is only 65-75 per cent of the weight of fresh segments put in the can. This is because of the osmotic diffusion of water from the fruit to the more concentrated syrup.

After the cans have been filled, it is necessary to expel most of the air dissolved or otherwise included in their contents. The conventional method is thermal exhaustion, whereby the open cans are passed through a bath of hot water until a temperature of 60°C-62°C is reached at the coldest point. A slight rocking motion may be given to the conveyor to facilitate release of air bubbles. As the air is expelled, a "mat" of water vapour is formed in the head-space of the can. After sealing and cooling, this mat condenses and a partial vacuum is obtained. The absence of air and good vacuum are important considerations for the prevention of internal corrosion of the can and for securing a reasonably long shelf-life for the product.

The exhausted cans are sealed and pasteurized. Pasteurization is achieved by boiling the cans in water. The cans may be put in crates which are then lowered into a hot bath (batch operation) or they may travel on a conveyor immersed in boiling water. The time required for pasteurization depends upon the size of the cans. Time and temperature data for the pasteurization of grape-fruit segments in different can sizes are given in most canning handbooks. The cans are thoroughly cooled after pasteurization. It is important to handle the cans with great care at this time, since grape-fruit segments are very fragile during the few days following production.

The two factors that most influence the quality of the final product are the initial condition of the fruit and the skill of the workers at the sectionizing table. Since the most important stage of production is carried out by hand and every single segment is handled at least once by the workers, special sanitary measures must be taken and strictly observed. All workers should cover their hair. The cleanliness of the hands is important. If possible, latex gloves should be used, to the benefit of product sanitation as well as for the protection of the workers from chemical injury to their skins.

Chilled grape-fruit segments

The method of production of chilled grape-fruit segments is the same as for canned grape-fruit. The product is generally packed in glass jars. Thermal exhaustion and pasteurization are omitted Sodium benzoate (about 0.1 per cent) is added as a preservative, and the product is stored under refrigeration. This product is a semi-preserve and should be kept at all times at a temperature of about 0°C.

Frozen segments

This is a relatively new product. When the usual process of quick-freezing commonly used for peaches, strawberries, etc. is applied to grape-fruit, the texture is impaired considerably. Although the flavour is excellent, the texture is decidedly inferior to that of the canned product. Application of more recent quick-freezing techniques such as liquid nitrogen freezing may result in a better product.

Chapter Ten

MISCELLANEOUS PRODUCTS AND BY-PRODUCTS

Essential oils

A few varieties of citrus fruit, among them Bergamot oranges and some limes, are grown exclusively for their oils. In the case of lemons, oil and juice have almost equal importance. In Italy, oil is considered the principal product. With oranges and grape-fruit, the oil is generally a by-product.

The method of oil recovery depends on the process used for juice extraction. With Taglith extractors (see chapter five, page 14), the oil is recovered before juice extraction in an operation in which the whole fruit is rasped under a jet of water. In the FMC extractor, juice and oil extraction take place simultaneously (chapter five, pages 15-16). Still another method very commonly used in the USA takes the peels after juice extraction and subjects them to pressure while the oil is washed away with water sprays. All of these methods recover only a small fraction of the oil actually present in the peel. However, the product known as cold-press oil is of superior quality.

In all three of the methods described, the essential oils are obtained in the form of emulsions with water. These are first screened to remove any solid debris and then centrifuged in several steps until a clear oil is obtained. The heavy (water) phase discharged from the centrifuges still contains some oil: this can be recirculated with the water used for sprays or steam-distilled to recover its oil.

The oil not released by cold-press methods may be recovered by steam distillation of the peels, but steam-distilled oil is considered inferior to cold-press products. At the present time, the supply of essential oils (especially orange) is in excess of demand and prices are low. Consequently, the economic prospects of increasing yields by steam distillation are not always attractive.

The largest part (90-98 per cent) of most citrus-peel oils consists of terpenes and sesquiterpenes that contribute little to the fragrance. "Concentrated" oils may be produced by distilling off the more volatile terpenes. While the "multi-fold" oils thus obtained are much in demand, the terpene by-products find only limited uses.

Essential oils may undergo deterioration by oxidation and polymerization. They should be preserved from high temperatures and sunlight. Refrigerated storage in metal drums, aluminium bottles or tin-plated cans is customary.

Pulp

The excess pulp removed from raw juice is an excellent, flavourful material for the manufacture of jams, jellies and bases for soft drinks. Like most commercial fruit pulps, it is stabilized by cooking and sold in barrels with added preservative. At present, this product has only limited demand. Therefore, many processors prefer to recover the soluble solids of the pulp for the manufacture of concentrate as described in chapter seven.

Processing of waste peel

For every ton of fruit processed, 500 to 600 kg of waste peel remain. Failure to convert this waste to salable products endangers the overall profitability of the packing operation and poses serious problems of disposal. For small-scale processing, an outlet for the peel as fresh cattle-feed may be found in the vicinity of the plant. However, large plants or groups of small factories must often resort to further processing of this material.

The chemurgical utilization of citrus peel, a great hope of the past, has reached its limit. The existing plants for the manufacture of peel chemicals (pectins, flavonoids) have a production capacity far in excess of market demand. Consequently, conversion to dry cattle-feed is still the principal outlet for waste peel. This is done as described below.

The peels are first disintegrated, mixed with lime and allowed to react for about 30 minutes. This treatment destroys the water-retention capacity of the pectins. Most of the water and soluble sugars can now be removed by simply squeezing the peels in a screw-press. The pressed waste, which contains about 65-70 per cent moisture, is dried in rotary kilns by direct counter-current contact with hot combustion gases. To prevent excessive heat damage, the dry material should be cooled immediately at the exit of the kiln. The product is packaged and stored in bags.

The liquid pressed from the peels (peel liquor) contains about 10 per cent sugars and some essential oil. The oil can be recovered by steam-stripping, but it is of poor quality and is used primarily in the chemical industry. The liquor may be concentrated to a dark, viscous fluid containing over 70 per cent solids and known as citrus molasses. It is mainly used for cattle-feed. It can be sold as such or mixed with dry feeds.

Another interesting utilization possibility for peel liquor is the manufacture of alcohol. Approximately 70 per cent of the soluble solids are fermentable sugars. The liquor is acidified to pH 4.0 and inoculated with an actively fermenting culture of a special yeast. Fermentation requires about three days. The resulting "beer" is then distilled to recover its alcohol. Due to the relatively high concentration of methyl alcohol, fusel oil and odorous residues, careful rectification is essential.

Candied products

These attractive and well-known products are usually prepared on a very small scale. They are used as confectionery products or as flavourings in baked goods. Usually only the peels are candied, but candied whole fruit (kumquats) and segments (mandarins) are also produced.

The peels are quartered and removed from the fruit by hand. The outer flavedo is removed by rasping or scouring. The inner surface is cleaned from adhering fruit and membranes. The peels are now cooked to soften the texture and extract most of the bitterness, after which they are drained and saturated with sugar by boiling in concentrated syrup. A candying process making use of vacuum kettles has been proposed. At a given time the vacuum in the kettle is released, and the syrup is thus forced into the peel tissue. Food colours are generally added to the syrup. Finally, the peels are drained, allowed to dry and then packaged.

Candying is a process that requires considerable empirical skill and a tremendous amount of handling. The equipment is simple. This process therefore is especially suitable for rural and home industries. The inner parts of the fruit may be utilized, in the same scale of operation, for jams and jellies. Obviously, these products have little significance as outlets for citrus crops.

Dehydrated citrus juices

The conversion of citrus juice to an "instant" powder by removal of almost all of its water has obvious economic advantages. Unfortunately, the technological difficulties encountered are tremendous.

Most of the early processes were based on vacuum drying, an extrapolation of vacuum concentration. However, the final stages of drying are extremely slow and the product melts into a sticky mass that must be solidified by chilling and then ground. A significant breakthrough came with the development of the "foam-mat" drying technique by workers at the Eastern and Western Research Laboratories of the United States Department of Agriculture. A continuous foam-mat process also has been developed in the USA by the American Machinery and Foundry Company. Finally, freeze-drying methods have also been applied to citrus juices.

The extremely labile character of citrus flavour, already discussed in chapter seven, page 23, is also the principal difficulty with dehydration; the flavour is completely lost in the process. Some retention is possible in the case of freeze-drying, but the beverage obtained by dissolving the powder in water is still far from the original juice in terms of flavour. The development of a solid citrus essence that could be added to the powders has been attempted. Grape-fruit juice, which has a "sturdier" flavour, yields an acceptable product, but the results with orange juice are still unsatisfactory.

At present, commercial dehydration of citrus juices is at an experimental stage. Small amounts of citrus powder (or crystals) are probably being produced for use in military rations, space programmes etc. Considerable research effort is devoted to this problem. Should the technological and economic difficulties find solutions through such efforts, a revolution in the entire set-up of citrus processing may be expected.

ANNEX

FEASIBILITY STUDIES FOR TWO SMALL CITRUS-PROCESSING PLANTS

The economics of any given citrus-processing operation will be strongly affected by local conditions. Some of these are the quality and cost of fruit; the length of the season and the extent of utilization of production facilities during the off-season; the costs of labour, utilities, packaging supplies and capital; local policy governing fruit supply and exports; proximity to the source of fruit and to the markets; and availability of technical and administrative know-how are all factors of cardinal significance. These factors vary within wide limits from one country to another.

Since the economic study presented here as an example is based on hypothetical conditions, it cannot demonstrate the profitability or non-profitability of any actual citrus-processing operation; it merely points out the relative weight of the different production cost items and the effect of operating conditions.

Description of the plant models

Two models are considered: Model A is a very small plant with an input capacity of 4 tons fruit per hour. Assuming 100 days of steady operation per year (1 shift per day), this capacity corresponds approximately to 3000 tons of fruit per year. Assuming also that the raw material consists of packing-house culls, such a plant would be used to absorb the culls from a total crop of 10,000-12,000 tons or a plantation area of 315-500 hectares, depending upon factors such as the age and variety of the trees and the agro-technical methods used. The packing-house would have a capacity of 250,000 boxes per year, which is also a small-to-medium size commonly encountered.

We shall assume that the plant is idle during the off season. Most of the labour force will be temporary workers, to whom salaries will be paid for four months only. A nucleus of only four skilled workers (including management) will be retained throughout the year, and it is assumed that even these workers will find part-time work in other operations such as an associated plant or office, so only 50 per cent of their off-season wages will be chargeable to the citrus-processing plant.

The plant will produce single-strength juice, packed in No. 2 cans, and essential oils. The waste peel will be sold as fresh feed at US$5.00 per ton, at the factory.

Because of the small capacity of the plant, an extraction line consisting of Taglith automatic extractors[1] has been selected. These extractors can be easily fitted with reamers of different sizes, thus permitting the handling of a variety of sizes of fruit with a limited number of extractors. Furthermore, these extractors can now be purchased, while other automatic extractors may only be leased at this time. At low capacity, it would be difficult to justify the minimum lease required.

It is assumed that all the products are exported. Easy access to export ports is essential. This is taken for granted, since the very existence of the citrus-packing operation also depends on this condition.

Model B is a larger plant, absorbing 6000 tons of fruit per season (about double the capacity of the smaller plant). Half of the fruit is processed for canned juice; the other half is converted to 6:1 hot-pack concentrate. All other conditions are identical with those described for Model A.

Explanation of other assumptions [2]

Equipment cost. The capital requirement for equipment is based on recent quotations and actual cost data from recently erected plants of similar size. This item may be considered as fairly accurate and less affected by local conditions than some of the others.

Buildings. The following cost factors are assumed. They may vary with local conditions.

Production area	$100/m²
Storage area	$ 60/m²
Office and laboratory	$ 80/m²

Erection costs

Installation	20 per cent of equipment cost
Design and supervision	10 per cent of physical plant
(includes running-in and process know-how)	

Working capital. Since most of the operating expenses are cash items that must be paid during a short period, while the returns from sales are expected to come in only during the off-season, ample working capital is necessary. An amount equal to the approximate running expenses for one year was assumed.

Operating cost factors

Fruit	$20/ton delivered
Unskilled labour	$200/month/man
Skilled labour	$350/month/man

[1] See text, chapter five, page 14.

[2] All cost estimates are in terms of United States dollars ($).

Operating cost factors (continued)

Cans (No.2) including labelling or printing	$4.00/100 cans
Cases	$0.12 each
Steam	$4.00/ton
Power	$2.00/100 kWh
Water	$0.10/m^3
Maintenance supplies	5 per cent of equipment cost per year
Depreciation	10 per cent of fixed capital per year
Interest on working capital	8 per cent per year
Sales expenses (transportation, commission, promotion)	15 per cent of sales

Product prices

Single-strength juice	$1.60/case of 12 No. 2 cans (FOB market port)
6:1 concentrate	$700/ton (FOB market port)
Essential oils	$3.00/kg
Peels	$5.00/ton, at plant

Capital requirements

Equipment	Plant A $1000	Plant B $1000
Receiving line and bins	13	18
Inspection, washing, sizing	9	10
Rasper	8	10
Juice extractors	20	26
Finishers	3	5
Pasteurizer and controls	5	6
Filler and sealer	17	17
Cooler	2	2
Labeller	3	3
Hand crater	1	1
Centrifuges	7	7
Evaporator	–	22
Concentrate pasteurizer	–	4
Concentrate filling and sealing	–	4
Concentrate cooling	–	2
Product pipes, pumps, vessels	4	8

Equipment (continued)

	Plant A $ 1000	Plant B $ 1000
Steam plant	12	20
Internal conveying, etc.	5	6
Laboratory	2	2
TOTALS	111	173

Buildings

	Area (m^2)	Plant A Cost ($1000)	Area (m^2)	Plant B Cost ($1000)
Production	300	30	400	40
Storage	300	18	400	24
Offices and laboratory	60	5	60	5
TOTALS		53		69

Summary of capital required

	Plant A $1000	Plant B $1000
Equipment	111	173
Erection	22	35
Buildings	53	69
Other civil-engineering works	10	12
Design and supervision	20	28
Total fixed capital	216	317
Working capital	200	300
TOTAL CAPITAL REQUIRED	416	617

Yearly operating expenses

Labour cost

	Number	Plant A Payroll ($1000)	Number	Plant B Payroll ($1000)
Unskilled (temporary)	20	16	35	28
Skilled (temporary)	5	7	8	11
Skilled (permanent)	4	11	4	11
TOTAL LABOUR PAYROLL		34		50

Supplies

	Quantities	Plant A ($1000)	Quantities	Plant B ($1000)
Fruit	3000 tons	60	6000 tons	120
No. 2 cans (thousands)	2300	92	2300	92
No. 10 cans (thousands)	–	–	56	9
Cases (thousands)	190	23	200	24
TOTAL SUPPLIES		175		245

Summary of operating expenses (per year)

	Plant A ($1000)	Plant B ($1000)
Supplies	175	245
Labour	34	50
Utilities	2	6
Maintenance	5	8
Depreciation	22	32
Interest of working capital	16	24
TOTAL PRODUCTION EXPENSES	254	365

Income

The output of the plant is computed on the basis of the following yields per ton of fruit:

Juice	450 liters (64.5 cases)
or	
Concentrate	75 liters (approx. 90 kg)
Essential oil	1 kg
Waste peel	550 kg

	Quantity	Plant A ($1000)	Quantity	Plant B ($1000)
Juice (cases of 12 no. 2 cans)	190,000	304	190,000	304
Concentrate (tons)	–	–	270	189
Essential oil (kg)	3,000	9	6,000	18
Peel (tons)	1,650	8	3,300	16
Total sales		321		527
less 15 per cent sales expenses		48		79
TOTAL INCOME		273		448

Summary of profitability

Our analysis shows a gross yearly profit of $19,000 for plant A and $83,000 for plant B, or 6 per cent and 15 per cent of the gross sales, respectively. Obviously, this conclusion can be only as valid as the assumptions upon which the analysis is based.

The importance of packaging material cost (see "Supplies") in the total expense calculations is instructive. This factor is the principal reason for the higher apparent profitability of plant B, where half of the juice is sold as concentrate.

Despite the generality of the assumptions, the analysis also shows that it is almost impossible to sell citrus products of the ordinary kind at present market prices if the cost of fruit is much higher that $20 per ton. Since such a price is considerably below the cost of growing and picking citrus fruit in most areas, such an operation can only survive if culls are the raw material. However, development of more concentrated products of superior quality that may secure a more favourable return per ton of fruit and the advent of cheaper packaging materials could change this situation completely.

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It is not intended to present here a comprehensive list of publications dealing with the various aspects of citrus technology, chemistry, biochemistry and physiology. Only a limited number of references, containing practical information on processes both conventional and recently developed are listed.

NOTE: The reader interested in citrus processing should also aquaint himself with the various official standards that govern manufacture of and trade in citrus products. Identification and quality standards have been issued by governmental agencies in the principal citrus-producing and -consuming countries such as the USA, UK, Israel, Italy and Spain. These standards are reviewed and amended frequently, and they cover the entire range of production: fresh fruit, juices, concentrates, bases for "ades" and the like, and citrus soft drinks, canned segments, essential oils, etc.

International standards for citrus products are being prepared by a special committee of the Food and Agriculture Organization of the United Nations.

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