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CITRUS PROCESSING IN THE UNITED STATES 1/

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Contents

Introduction

My purpose is to describe the present state of the citrus-processing industry in the United States. Our citrus industry is very large. The current value of the U.S. citrus crop (as fruit) is about $870 million, annually. Because much of this fruit is processed into various citrus products, the total contribution of the citrus industry to the U.S. economy is several times this amount. With 1/4 of the world's production of oranges and lemons, and 3/4 of the grapefruit, we produce more citrus fruit than any other nation in the world.

Table I

1972 Citrus Fruit Production, U.S. and World

Type of Fruit	Production, metric tons/year U.S.	World	U.S. Percentage of Total
Oranges	6.1×10^6	23.0×10^6	26%
Grapefruit	2.2×10^6	3.0×10^6	73%
Lemons	0.6×10^6	2.1×10^6	28%

I do not claim that our industry is the most advanced in the world or that it ought to serve as a model for other nations to imitate. Not all the arts we practice may be immediately applicable elsewhere, or even desirable. That will be for you to judge.

While we do export citrus fruit and products, our foreign trade is a small percentage of our total production. Nevertheless, because the United States is a very large common market territory, and the most highly-urbanized nation in the world, with exceptionally long domestic food-supply lines, we can support a highly-developed citrus-processing industry.

Our citrus-growing regions are located in humid, subtropical areas along the gulf coast, principally Florida, in parts of the southwestern desert, and in the Mediterranean-type climatic regions of southern California. On the other hand, our largest population centres are in the Northeast. New York and Chicago are 1500 kilometers or more from the citrus-growing regions. Shipping costs are therefore of considerable significance, and real savings can be achieved by weight and volume reductions. In March, 1974, I made a spot survey of retail citrus fruit and product prices which showed that frozen citrus juice concentrates are being delivered to U.S. consumers at less cost than the equivalent weight of fresh fruit. Such products are therefore economically efficient in addition to any other attractiveness they might have for the consumer, such as convenience and year-round availability.

Table II

Retail orange prices, March 1974

Type of fruit or product	Cost of edible portions, solids basis
Navel Oranges	$5.30/kilo of orange solids
Valencia Oranges	$7.95 " " " "
Frozen Concentrate (highest grade)	$3.93 " " " "
Frozen Concentrate (medium grade)	$3.22 " " " "

These prices are quite comparable to our domestic prices for other fruits and also for tomato products. The average American consumer does not regard citrus fruit or citrus products as a luxury.

Size of the Processing Industry

The proportion of the total U.S. citrus crop that is processed is shown in Table III.

Table III

Amount of U.S. Citrus Fruit Processed

Type of Fruit	Production, metric ton	% Processed
Oranges	7.0×10^6	25% - 70%
Grapefruit	2.2×10^6	50% - 60%
Lemons	0.6×10^6	40% - 50%

The relative quantities of various products are listed in Table IV.

Table IV

Amount and Type of Citrus Products

Type of Product	Amount Produced	Single-strength equivalent
Frozen orange juice conc.	506×10^6 liters (42° brix)	[illegible],020 $\times 10^6$ kg.
Canned grapefruit juice	27×10^6 cases (single-strength)	300×10^6 kg.
Canned orange juice	14×10^6 cases "	160×10^6 kg.
Frozen grapefruit juice conc.	33×10^6 liters	130×10^6 kg.
Orange-grapefruit blends	2×10^6 cases	23×10^6 kg.
Grapefruit sections	2.6×10^6 cases	N/A

Of the six products listed in Table IV, three have tripled in volume during the past decade. These are the two frozen juice concentrates, and canned single-strength grapefruit juice. The other three have remained static, or have decreased slightly.

Effect of Processing on Consumption Patterns

The dominant edible citrus product is, of course, frozen concentrated orange juice. Since its introduction about 1945, its growth has been remarkably steady, and shows no signs of levelling off in the immediate future. It has produced a dramatic change in consumer behavior. Until 1945, most citrus fruit was eaten fresh. Only a relatively small amount was processed, principally into canned single-strength juice. During the two decades 1920-1940, the per capita consumption of citrus fruit steadily increased, as more and more acreage came into production (bearing acreage increased 2-1/2 fold during that period). The American consumer appeardd to reach a saturation point for citrus products in 1945, at about the level of 40 kg per person per year. With the introduction of frozen concentrates into the market, there then began a sharp decrease in per capita consumption of whole citrus fruit, which has now levelled off at or below 1920 levels. Meanwhile, total per capita consumption remained fairly steady, and may now be again on the increase. (Since 1940, bearing acreage has increased only about 50 percent but is now increasing at about 5% per year.)

The net effect of the availability of frozen orange juice concentrate has been to stabilize the commodity against the attrition of per capita consumption that has affected a number of other agricultural commodities in the United States.

We are an affluent society, and affluence produces changes in eating habits. In the United States for many years the trend has been toward higher consumption of meat. Meanwhile, total per capita calorie intake has remained constant, or decreased slightly. This has resulted in rather sharp drops in per capita consumption of flour and cereal products, eggs, dairy products, and noncitrus fruits. By contrast, per capita utilization of citrus (and potatoes) has remained virtually steady, apperently only because of the availability of convenient processed forms of these two commodities.

Nutritional Significance in the U.S. Dietary

Citrus fruits contribute significant amounts of caloric energy and vitamins to the American diet, and the proportion is increasing slowly. At present we receive about 2% of our carbohydrate calories, 1.3% of our vitamin A, 2.4% of our vitamin B_1, and 24% of our vitamin C from citrus fruit. The proportion of these nutrients contributed by citrus fruits has increased by about 10% during the last 15 years.

But the story of frozen juice concentrates, while very important, is by no means the whole story of citrus processing, as everyone knows. It is only the letest and perhaps the most spectacularly successful development to come along.

TYPES OF CITRUS PRODUCTS

Citrus processing probably began with the production of hand-pressed peel oils. This immensely laborious process involved pressing hand-held fruit against a sponge, which received the extruded oils, and prevented them from being reabsorbed by the peel when the pressure was removed. Today, mechanical processing of and/or distillation of oils is an important adjunct to fruit processing, but is by no means the principal process. Figure I indicates some of the major steps in citrus fruit processing, and lists the most important products and by-products.

I will now attempt to give a brief description of the manufacture of several of these products. Limitations of space and time will not permit me to go into great detail about any one of them. The main message I would like to leave with you is simply this: the manufacture of each of these products can be almost totally mechanized, even to the point of automatic sorting of fruit by skin colour about which I will have more to say in a moment.

Sorting

Sorting is a necessary part of the overall processing scheme. Frequently the fruit must be separated in various grades according to size, maturity, and condition, with some grades going to the fresh market and others into processed products. Automated sorting by size is a very old art, and there is no particular need to discuss it here. Automated sorting by colour is a much newer development, though now widely practiced.

One common type of colour sorter operates in the following manner: the fruit is singulated and then allowed to fall a short distance into a moving cup which is equipped with a hinged trapdoor. While in free fall, the fruit is illuminated by light of appropriate wavelengths. The reflectance of the fruit is observed by means of photoelectric cells, usually several in number, dispersed around the path of fall of the fruit. The signal produced by the photoelectric cells is massaged, averaged, and through some electronic treachery triggers the release of the fruit from the cup at the instant the cup passes over one of several conveyors that collect fruit of a specific colour. These machines are capable of separating fruit into as many as 4 or 5 different colour classes.

Concentration of Citrus Juices

Citrus juices are normally concentrated 4-fold (i.e., to about 42° Brix) for sale as frozen concentrates. Much of the volatile flavour and aroma are removed along with the vapour during concentration. Formerly, some of the flavour was restored by over-concentrating the juice (e.g., to 60° Brix) and diluting ("cutting-back") this concentrate with single-strength juice. Now, however, it has become possible to recover an essence fraction from the evaporators and restore enough of this to the juice to produce a good-flavoured concentrate without over-concentration and cut-back.

This has come about largely through the adoption by the industry of the so-called TASTE evaporators. (TASTE is a rather contrived acronym for Thermally Accelerated Short-Time Evaporator.) Basically, the TASTE evaporator consists of a multiple-stage, multiple-effect system, in which each stage consists of a long (12 m), vertical tube-bundle. Juice flows downward on the tube side and steam or vapor condenses on the shell side. Typically, three or four effects and 4-6 stages are used. The first several stages correspond to different effects, but the last 2 or 3 are usually serial sections of the final effect. In older installations the first stage may be the first effect, and so on, but in later installations the first stage of concentration may occur in the second evaporative effect, and vice-versa.

In this version, the juice is partially preheated (to about 75° C) and evaporated in stage 1; heat being supplied by means of vapours produced in the second stage. The concentrate leaving the first stage is then further heated (to about 95° C) and sent to the second stage. The second stage, containing the fully-heated juice, is heated by means of condensing steam, and is therefore technically the first effect. The vapours produced in the first stage (second effect) are used to heat the third, fourth, and fifth stages, which together comprise the third effect. The concentrate from the final stage (about 40° C) is flash-cooled to 20° C or less.

Essence is produced by tapping vapors from the shell-side of effects 2 or 3. These "essences" (really vapour fractions) may be further fractionated and concentrated as desired for their end use.

One of the main virtues of the TASTE evaporator (apart from the energy economies of multiple-effect operation) is its short residence time and relatively compact size. It does, naturally, require considerably more energy to operate than the theoretical minimum that would be required to boil down the juice in triple effect. Additional steam is required to operate the ejectors for removal of noncondensables and for flash-cooling the product; pumps are needed for transportation of the concentrate between stages. Some data obtained from the manufacture indicates a steam consumption of about 0.4 KG/Kg of water evaporated.

Freezing

Cooled concentrates may be slush-frozen, typically in a scraped-surface heat exchanger, filled into containers, and hard-frozen in an air-blast freezer.

Oil Extraction

A variety of mechanical presses have been developed for extracting peel oils. This is now a rather old art. All have one principle in common: The machine must be constructed so that the oil is transported away from the spongy peel residue before the pressure is released--otherwise the oil will immediately be reabsorbed. Some machines accomplish this by use of grooved pressing rolls. Another widely-used extractor presses the fruit between interlocking metal fingers so that the oil oozes out between them and may be collected separately from the juice.

Alternatively, the flavedo may be separated by cutting or abrading it away from the fruit. By extracting the comminuted peel with water an emulsion of the oil is obtained, and the oil is recovered by centrifugation.

Table V

World Production of Citrus Oils

Type of Oil	Production, Metric Tons/Year
Sweet Orange	2000
Bitter Orange	30
Lemon	1000
Lime	400

Since about 2 kilos of oil are recovered from a metric ton of fruit, the total world of production of 3400 metric tons of oil represents about 2 million metric tons of fruit processed for oil recovery. (A relatively small percentage of the oranges, but perhaps half of all lemons.)

<u>Pectin</u>

Citrus peels contain pectin, which finds a number of commercial uses; much of it becomes an ingredient of fruit preserves, jams, and jellies. Typically, the pectin is extracted from shredded citrus peels with about 16 parts of hot, acidified water at 85-95° C, and pH 2-3. Starches and dextrins which appear in the extract along with the pectin are enzymatically hydrolyzed. Following hydrolysis, the extract is vacuum concentrated about 4-fold. This concentrate may be sold as liquid pectin. Alternatively the pectin can be precipitated (e.g., with alcohol), dried, and marketed in solid form.

<u>Citric Acid</u>

Although most citric acid is now being produced by fermentation, there may be instances when its extraction from low-value fruit is feasible. To recover citric acid, oil-free fruit (lemon) juice is allowed to ferment several days with natural yeasts to destroy pectin and sugars. The fermented juice, which contains 3-4 percent citric acid, is filtered and the acid precipitated by addition of lime ($CaOH_2$). The precipate may be sold as calcium citrate. Alternatively citric acid may be recovered by redissolving calcium citrate in a solution of sulfuric acid. In this case the calcium precipitates as calcium sulfate, leaving behind a solution of citric acid. This solution is concentrated to the degree necessary to produce crystalline citric acid.

Disposition of Pomace

The pomace remaining after extraction of juice, oils, and pectin finds use as animal feed, primarily as a source of caloric energy.

Sterile Products

A discussion of citrus processing would not be complete without some mention of canned juices and fruit sections. Such products have a long history of use, although they are a rather small fraction of the total citrus market in the United States, and (except for canned single-strength grapefruit juice) their volume has not grown in recent years. Both orange and grapefruit juices are available, as are canned grapefruit sections. No particularly novel technology is involved in the production of sterilized citrus products. Grapefruit-sectioning machines have been developed. The ones that I have seen have been a marvel of complexity, as you might imagine. The main engineering problem in this case is accurate placement of the sectioning knives at the divisions between sections,despite the highly-irregular topography of the fruit.

SIDE-EFFECTS

In this day and age it is not possible to consider any major change in technology without taking into account the side-effects it may produce. (In the United States concern over side-effects has been institutionalized in the form of an Office of Technology Assessment, as arm of the Congress.)

One side-effect of orange-processing technology, alluded to earlier, was a change in the pattern of fruit utilization. Americans now eat fewer fresh oranges than they used to. There has in fact been virtually no increase in the production of navel oranges (a variety that is not processed) in California since at least 1930. Some of this lack of growth may be attributed to displacement of orange groves by urban expansion in the Los Angeles basin. But in some measure it must also be due to lack of increase in the demand for fresh fruit, in consequence of the availability of frozen orange juice. Since orchardists cannot quickly convert from growing fresh-market varieties to processing varieties (and some might not be able to convert at all, because of differences in climatic requirements), new technology is bound to introduce stresses in an existing industry. This is one kind of side-effect that has to be considered.

A second kind of side-effect concerns energy and other resources. The manufacture, packaging, storage, and distribution of frozen orange juice uses large amounts of energy. Energy is required not only for processing itself, but for making processing machinery, for manufacture of packages, for freezing and cold storage, as well as for transportation. It is likely that far more nonrenewable resources are consumed in packaging of processed foods than in the marketing of raw products. On the other hand, the shipment and marketing of fresh produce also requires energy. Some new studies indicate that the total energy required to deliver processed fruit may be 10 times that required for unprocessed products. In America, where labour costs have traditionally been high and fuels cheap, the delivered cost of processed foods has been competitive with fresh food. This has been enough to justify them, and we have not until recently, at least, had to be particularly concerned about the effects of energy consumption on our foreign-payment situation. Elsewhere the situation might be different and the effects of new technology on the national energy bill might be a very important consideration.

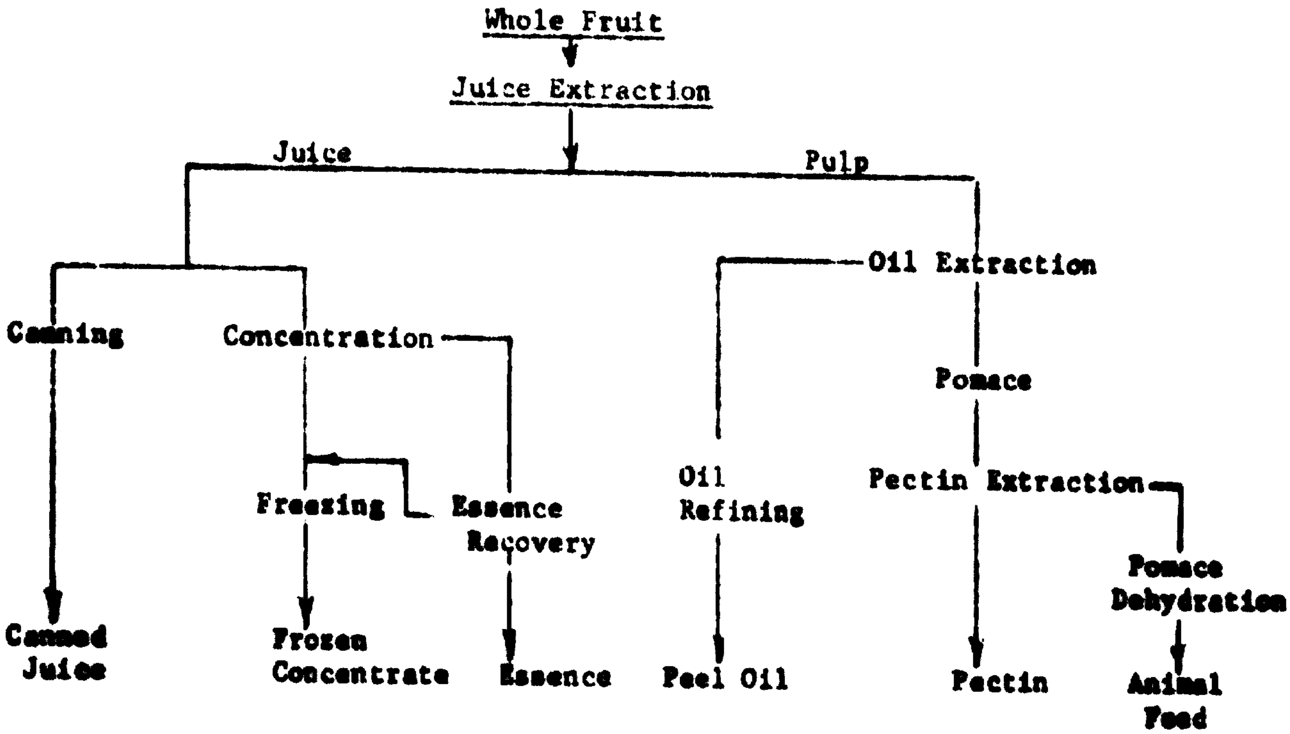
Finally, a few words about environmental problems. Food processing does not ordinarily create any pollutant that would not be created by use of the unprocessed commodity: it merely concentrates the pollutant in specific locations. But it is one thing to have a few million tons of orange pomace distributed over the surface of the globe, and quite another to have it all deposited within the boundaries of the state of Florida, where it could annually create a pile about 1Km on a side and several meters deep. Florida being a rather small, flat state, a substantial part of it could disappear from view by the end of century unless action were taken to dispose of citrus pomace by some method other than land fill. Using it as feed for ruminant animals is an obvious step toward reducing its volume, though perhaps not its magnitude as a pollution problem. In this way, much of it leaves the locale by air (as CO_2), some additional goes out on the hoof, and only the indigestible remainder must be dealt with in situ--but it must be dealt with.

To launch into a discussion of disposition of manures would seem to be far afield from a discussion of citrus processing and I will, in fact, not dwell on the subject at any length. However, I would like to emphasize one consequence of the American historical experience of progressive urbanization, mechanization, automation (and all the other "ations" we have fallen heir to): we can no longer single out one kind of activity, such as citrus processing, and consider it alone, without also considering its side-effects and interactions in a larger context.

It may seem that I am telling you that a presentation such as this one is an anachronism. That is not so. Rather, I am suggesting that in telling you something about citrus processing, I have told you only one small part of a much larger and very interesting story; one that is bringing about revolutionary changes in my field of agricultural and food research. But that is a subject for another time and place.

Figure I

Schematic Diagram of Citrus Processing



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