Chapter II

LITERATURE REVIEW

2.1 What is Evaporation

According to Earle (1960) and Borgstrom (1968), evaporation refers to the removal of water from a fluid food material which contains more water than is required in the final product through vaporization. It becomes more than simply an engineering exercise in securing the thermodynamically most effective systems, since some effects, resulting from both the biological nature of the raw materials and the consumer organoleptic/nutritional acceptance of the products made, become equally important. In general, the field of evaporation is well documented as a subject in the broad scope of chemical engineering, however, when considered in the more specific context of the food industries, information is harder to come by.

Borgstrom pointed out that the purpose of the evaporator was to permit the transfer of heat, the vaporization of water, and the removal of fluid droplets from the vapor before it left the evaporator. The basic factors which affect the rate of evaporation were summarized by Earle as:

1. the rate at which heat can be transferred to the liquid,
2. the quantity of heat required to evaporate each pound of water,

3. the maximum allowable temperature of the liquid,

4. the pressure at which the evaporation takes place,

5. any changes which may occur in the foodstuff during the course of the evaporation process.

Earle (1966), Bielig (1973), and Werner (1973) stated that the evaporator had two principal functions, to exchange heat and to separate the vapor that was formed from the liquid. However, it usually consists of three functional units:

1. the heat exchanger, to supply sensible and latent heat to the juice,

2. the evaporating unit, where the liquid boils and evaporates,

3. the separator in which the vapor leaves the liquid and passes off to the condenser.

Important practical considerations in evaporators were suggested by Earle as:

1. the maximum allowable temperature, which may be substantially below 100°C, depends on the nature of foods being evaporated,

2. the promotion of circulation of the liquid across the heat transfer surfaces, to attain reasonably high heat transfer coefficients and to prevent any local overheating,

3. the viscosity of fluid which will often increase substantially as the concentration of the dissolved materials increases,

4. any tendency to foam which makes separation of liquid and vapor difficult.

2.2 Consideration of Fruit Juices and Fruit Juice Concentration

Robbins and Gresswell (1971) mentioned that the fruit juices and their processing has been a development of the present century, particularly of the past 30 years. It has been pointed out by Bielig and Werner that the world production of fruit juices was approximated as 22.7 million hectolitres, of which at least one-fifth was concentrated fruit juice. They also claimed that citrus concentrates formed the bulk of the production, and that its processing was a specialised industry because of its nature.

Many species of citrus fruits were found originated in the tropical areas including the South East Asia. Among them those well known were listed by Tressler and Joslyn[1] as:

Citrus reticulata Blanco (Mandarins)

Citrus nobilis Lour

Citrus sinensis Linn or aurantium

Citrus grandis Linn or maxima (Pummelo)

and Citrus aulantifolia Swingle

Citrus reticulata Blanco is the enormous crops grown for fresh consumption with high popularity. It has a high Brix/acid ratio of

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[1]Donald K. Tressler, and Maynard A.Joslyn, Fruit and Vegetable Juice Processing Technology (Westport, Connecticut: The Avi Publishing Company, Inc.,1961),p.841.

over 11, but low content of vitamin C, as shown in Table 1 (1.)

Table 1. Analysis of Fresh Citrus reticulata Blanco Juice

Bx	Vit.C mg/100g	pH	citric acid g/100g	total sugar Percent	reducing sugar Percent
9	46.94	4.0	1.19	4.02	3.91
9	46.07	4.2	1.09	3.39	3.28
14	44.08	4.1	0.43	3.17	3.09
10	31.09	4.1	0.45	3.51	3.42
10	35.72	4.4	0.53	3.34	3.21
10	26.79	4.4	0.40	3.63	3.56
9	29.49	3.9	0.51	3.06	2.94
9	23.86	4.3	0.38	3.10	3.02
10.5	35.96	4.4	0.36	4.51	4.43
10.5	34.67	4.1	0.32	4.48	4.39

It was found by Wirada et al (1961) that it was not suitable to concentrate Citrus reticulata Blanco juice since it has separation of peel causing some defficulty during extraction, easily changes in color and flavor, and also develops bitter taste. Nevertheless, according to the standard No.99-2517 of Thai Industrial Standard Institute, it can be used for further 'cut back' process with Citrus sinensis Linn to make proper fresh orange juice. The Citrus

[1]Wirada, et al. Re. No.171 Department of Science, Ministry of Industry, Thailand, 1961. (Ref.No.4 in Thai)

reticulata Blanco itself has higher degree of total soluble solids than that of Citrus sinensis Linn., thus the evaporation will consume less power

2.3 Fresh Orange Juice and Orange Beverage

The juice-containing bodies of the mature fruit are closely compacted, club-shaped vesicles which completely fill the segments and an attached to the walls with small hair-like papillae. Multicellular in structure, the extremely thin-walled cells contain, besides juice, tho colour-bearing yellow chromatophores. Oil droplets embedded within the cellular tissue occur in the central part of each juice vesicles.

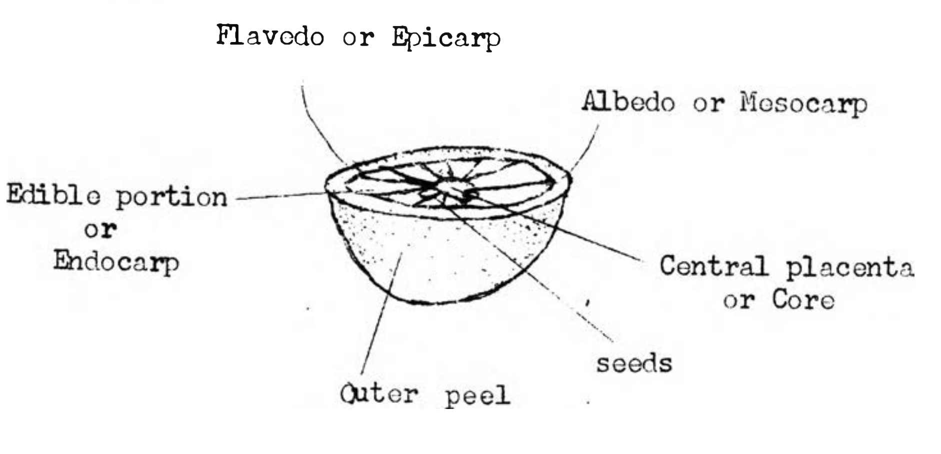

Figure 1 . Macroscopic structure of a halved orange.(1)

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[1]Walton B. Sinclair, The Orange Its Biochemistry and Physiology (The University of California Printing Department, 1961), p. frontispiece.

Substances responsible for some of the bitterness developing in the juice are located chiefly in the carpillary membranes, the vascular bundles, the spongy pith, and the inner spongy tissue (albedo) of the peel. The seeds also contain limonin, which is intensely bitter. Pectic substances and pectic enzymes are present largely in the inner peel.

The composition of the fruit (Citrus reticulata Blanco) was analysed and reported as follow:

Table 2. Analysis of Orange Composition(1)

Component	% by weight
Juice	40 - 45
Flavedo (outer peel)	8 - 10
Albedo (inner peel)	15 - 30
Rag & pulp	20 - 30
seeds	0 - 40

Dinsmore and Nagy (1972) mentioned that the fresh tasts of orange juice was a difficult property to preserve over long periods of storage. Unless juice is kept refrigerated to temperatures close to freezing a disagreable odor and off-flavor developed.

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[1] Donald K. Tressler, and Maynard, A. Joslyn, Fruit and Vegetable Juice Processing Technology (Westport, Connecticut. The Avi Publishing Company Inc.,1961), p.841.

Tressler and Joslyn (1961) further stated that, orange juice, after extraction from the fruit, would contain suspended matter, varying in type and quantity with the method used in extracting the juice. The larger pieces of pulp, obtained from the tissues surrounding the juice sacs, and particularly the seeds, add neither to the appearance nor to the flavor of the juice and result in a more rapid deterioration. Those coarse particles should generally be removed first. The method of screening used should be such as to cause little pressing and grinding, to produce a juice of minimum settling of solids and as free as possible from objectionable bitterness which is obtained if the rag and seeds are crushed and torn. They emphasized that all this should be accomplished with the least possible exposure to air, and with no metallic contamination.

Robbins and Gresswell stated that as the fruit was halved and reamed by hand it resulted in a slow production rate with oxidation of the juice constituents, and loss of cloud due to natural pectinesterase activity which broke the fruit pectin into galacturonic acid or its low polymers, all of which were soluble. Bielig and Werner explained that it was apparent that if the cloud nature of the juice were to be retained, this pectic enzyme must be inactivated. Robbins and Gresswell also stated that, another difficulty was the acquisition of bitter flavors arising from the pith or albedo included with fruit flesh. Borgstrom found out that on the basis of inactivating pectic enzymes, desirable temperature levels for heat processing of orange juice were 99°C for single strength juice and

104.5°C for concentrated juice. Robbins and Gresswell stated that, this process, however, as low as 80°C, resulted in loss of volatile constituents and the present of cooked flavors.

Lime and Cruse (1972) pointed that most orange flavored beverages currently marketed had little cloud and body, low or no suspended solids content, and low or no vitamin C content, as shown in Table 3[1]. Artificial color was also added.

Table 3. Analysis of Marketed Orange Juice Beverage Distributed in Thailand

Trade name	Brix	pH	acidity as citric acid %	vit.C mg/100ml
A	12	2.8	0.19	0.28
B	13	3.0	0.37	0.30
C	13	2.8	0.22	none
D	11	2.8	0.35	0.07
E	12	2.8	0.28	0.33
F	12	3.0	0.29	0.22

These aspects may be desirable from an economic and manufacturing standpoint, there still appears to be a market for a beverage having improved pulp, body, and cloud characteristics and containing as much of the natural fruit as possible.

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[1] Wirada, et al, Re, No.171 Department of Science, Ministry of Industry, Thailand, 1961, Data from 6 trademark distributed in Thailand (Ref.No.4 in Thai)

2.4 The Concentration of Orange Juice and Its Problems

Borgstrom and Earle mentioned that the concentration, the removal of water while retaining the liquid condition, was originally adopted for preventing wastage in years of surplus or to facilitate distribution and export. Bielig, Werner, and Borgstrom pointed out that the methods were closely related and in all cases accomplished by

1. heating,
2. vacuum treatment,
3. freezing,
4. the addition of solids (Like that in making condensed milk and fruit syrup, the relative water content is reduced by introducing solids, chiefly sugar. The biochemical effects of concentration are largely favorably showing the rate of several oxidative changes, basically by reducing the amount of air and oxygen dissolved in the syrup).

Borgstrom also claimed that the concentration of fruit juice, prior to 1940, was largely used in preparing catsup and as ingredient in soft drinks, where moderate flavor modification was less objectionable. Many processors like Bielig, Robbins, etc., have already appreciated the advantages of concentrated fruit juice in terms of:

1. Reduction of liquid volume to reduce storage, packaging, and transportation cost provides facilities for straight juice processing.

2. The heat treatment of the process will inhibit enzyme activity to prevent enzymatic browning reactions and other enzymatic reactions, and also destroy the original micro-organisms to enable the product to be preserved for a prolonged or infinite period of time.

3. The increase of soluble fruit solids also increase microbiological stability.

Clarke (1971) explained that the evaporation of fruit juices provided problems of first importance to the flavor of all fruit juices-the loss of volatile flavor substances. It is obvious that if water is being evaporated from a liquid, then the more or less volatile components will also be removed as vapor, to an extent dependent upon their relative volatility to water.

Clarke and Borgstrom have faced other problems associated with the concentration of liquid foodstuffs:

1. the foaming potential, which makes difficult the separation of vapor from concentrated liquors,

2. the fouling of heat transfer surfaces by already suspended or developed insolubilised matter,

3. the use of temperature that may be inadequate to kill mould spores,

4. the viscosity or consistency of the fluid, as water evaporates from the fluid, the consistency changes and, subsequently, the heat transfer rate changes, since as water is removed the boiling point of the fluid rises, then it reduces the heat transfer rate from

tho heating medium.

5. the need to have hygienic conditions of design and operation.

2.5 Methods of Concentration of Orange Juice

Many methods of concentration have been introduced and gradually developed as outlined below:

2.5.1 Open kettle pan

It is the most simple method and cheapest evaporator but it results in caramelization of the sugars in the juice undergoing concentration and in excessive loss of flavor by evaporation and decomposition through heating. Wiegand (1971), Gray (1971) and Heid (1967) pointed out that, this made the product to have poor taste and aroma characteristics. They also stated that, since orange juice was considered as heat sensitive food material, it was necessary to avoid boiling temperatures above 60° to 70°C. On the other hand it is very costly to operate with boiling temperatures below 40°C, even some evaporators have been designed to boil at as low as 21°C.

2.5.2 Vacuum concentration

In order to lower the boiling point of liquid, the atmospheric pressure is reduced by applying a vacuum. Many of the harmful effects of high boiling temperature on fruit juices are thus avoided. Although the heat required to evaporate either under vacuum or atmospheric pressure is not quite different in the latent heat of vaporization of water, the heat required to bring the liquid to the boiling point in vacuum is less. Wiegand pointed out that the disadvantages of this evaporator was that, lower temperatures not only resulted in a very great increase of the cooling water concumption, but also in a considerable increase of the measurements of the evaporator, for one reason because of the higher vacuum required and for another because of the higher viscosity of the product with its lower heat transfer. Unfortunately, as found by Robbins and Gresswell it made little difference to the general acceptability of the products.

Further application of this type of evaporator is in the form of double-and triple-effect vacuum evaporators.

2.5.3 Freeze concentration

Borgstrom stated that this method was introduced in the 1940's. Woollen (1969) commented that it relied on the observation that solution freezed into crystals of pure solvent until the solution had been concentrated to the eutectic point, at which stage the whole solution freezed. Fresh orange juice was frozen and let thawed. Centrifugation or filtration was resorted to separate out the concentrate which retained a high percentage of volatile flavors. Woollen (1969) and Lowe and King (1974) pointed out that there were, however, certain unavoidable entrainment losses of juices with the ice mass and the degree of concentration of juice was limited by the eutectic point of the juice concerned and was usually not greater than 50^{o} Brix. Lowe and King also observed some changes in the colloid suspensions of the juice. Bitterness was also detected.

2.5.4 Reverse osmosis

Wollen concluded that osmosis was the effect occuring when a solution was separated from a volume of the solvent in the solution by a semi-permeable membrane. It resulted in the passage of the solvent through the membrane and into the solution which thereby became progressively diluted. This migration of the solvent could be halted or reversed by applying a pressure to the solution which was equal to or greater than the osmotic pressure developed by the solvent. This development has applied to the de-salination of sea-water and latterly to the concentration of fruit juices. There are still some difficulties of the membranes which have to be permeable yet withstand pressure of the order of 500 lb/in^{2}.

2.5.5 Slush evaporation

The process was proposed and initially examined by Chandrasekaran and King (1971,1973). The feed juice was in a partly solid, partly liquid state, and then the drying mechanism was a combination of vaporization and sublimation. Lowe and King found that the aroma losses decreased with lower temperatures and also the solids loss increased with decreasing temperature in this process. They suggested that it was necessary to find an optimal temperature balancing between these effects for commercial uses. They still doubted whether an economically high enough drying/evaporation rate could be achieved.

2.5.6 Falling film/Thin film evaporator

The principle of the falling-film evaporator was discovered at the beginning of this century, and become important in the chemical and food industries. Robbins and Gresswell stated that climbing film evaporators were well established in the beet sugar industry before 1900, and application was then for fruit juices. Wiegand (1971) claimed that it was possible to use the same principle to build evaporators suited for the concentration of fruit juices to any specific requirements.

Wiegand explained that, in the evaporators, the liquid was caused to flow down the heating surface, covering the surface of the plate with a thin layer of liquid. It was usually to operate under reduced pressure.Bielig and Werner pointed out that the liquid to be concentrated must enter the evaporator at a temperature very close to the boiling point in the evaporator. Wiegand added that this was to ensure that the liquid boiled immediately as it entered to contact with the heating surface, and that the driving effect of the vapor flow took effect immediately and improved the heat transfer. He also suggested that only if this condition was fulfilled, could the heating surface of tho evaporator be properly utilised. If it was not fulfilled then no evaporation occurred, but only preheating took place. The liquid (to be evaporated) flowed under gravity along the plate. There was no static liquid on the plate, but only an acceleration of the downward flow of the more viscous liquid.

Gray (1971) pointed out that the film evaporators, by whichever means the film was produced, required the heat transfer surface to be continuously wetted. It was necessary to design the evaporators properly, for a certain minimum liquid rate per unit width of heat transfer surface to be maintained. Wiegand stated that the size of this surface, required for predetermined evaporating output, was proportional to the temperature difference. For a rectangular surface, with a certain heating area, it might have any different side measurements, i.e. broad and short, or long and narrow. He also pointed that the narrower the surface, the greater was the so-called 'liquid load'. Wiegand and Gray found that this liquid load must never be too small, as otherwise there was a danger of dry spots forming on the heating surface, with consequent burning of the liquid, incrustations on the plates, increasing fouling, and resulting poor heat transfer coefficients. Moreover, Wiegand pointed out that, higher liquid loads resulted in a better heat transfer from the heating surface to the liquid to be evaporated. The temperature difference between the heating and boiling temperature had necessarily to be of a certain degree to avoid the cease of evaporation.

Wiegand also claimed that, other types of evaporator caused foaming during evaporation. On account of the short residence time, the film evaporator was rated for a very sensitive evaporation. The small liquid content avoided foaming problems and losses through this were avoided. No mechanical or thermal energy was required to make the liquid flow over the heating surface.

Fleming and Hunter (1970) suggested that it was possible to establish an ideal unit for thin film evaporator with these characteristics:

1. a mechanical aid to the evaporator to create an agitated thin film of fruit juice,

2. the mechanism producing the thin film should not scrap the heating surface because once the heating surface has been bared, hot spots occur causing burning-on the product,

3. the mechanism producing the thin film should not have too great a clearance between the blade tip and the heating surface or the processing liquor on the heating is not sufficiently agitated and again burns-on degrading the product,

4. the retention time in the unit should be short,

5. the unit would have to be capable of handling a wide range of viscosities.

2.6 Evaporation Ratios/Concentration Ratios

Bielig, Werner, and Wiegand defined an evaporation ratio as the feed quantity to the concentrate quantity or as the concentration of the output concentrate to the initial concentration of the juice input.

$$e = F/E$$

$$\text{or} \quad e = C_E/C_F$$

where e = evaporation, or concentration, ratios

F = quantities of feed

E = quantities of concentrate

C_E = concentration of the output juice concentrate

C_F = initial concentration of the input juice

The effect of concentration ratio on the performance of an evaporator was explained by Gray. He found that at the end of an evaporating path there was insufficient liquid to maintain proper wetting, recirculation must be used to bring this quantity up to the minimum. This is most desirable in evaporator dealing with heat sensitive materials like fruit juices. As whenever recirculation is employed the residence time of some of the product is increased substantially, even if the mean residence time is not too greatly affected, which will result in product quality.

To increase the possible concentration ratio with the minimum product rate, it is necessary to either

1. increase the heat transfer coefficient,

or 2. increase the overall temperature difference, (but it is generally limited by the maximum permissible processing temperature)

or 3. increase the evaporation area.

2.7 The Recovery of Volatile Substances

Robbins and Gresswell concluded that, although there were many types of evaporator had been tried for fruit juices, the results were not satisfied yet, so far as flavor retention was concerned. Even the most careful evaporating process could not prevent the loss of valuable volatile aroma. The reasons are that:

1. the original juice being deficient in some respect, or having deteriorated in transit to the test evaporator

2. fruit juices flavors must be inherently labile and would never be evaporated successfully

3. the heat treatment at any stages during the processing, e.g. the pasteurization of fruit juice which require a certain level of heat to inactivate the enzyme activity and to destroy micro-organisms

4. the initial dissolved solids as found by Lowe and King(1974) that aroma retentions increased in most process with increasing initial dissolved solids concentration since the loss of volatiles was governed by a diffusion mechanism.

Charke explained that the loss of volatile substances as important flavor contributors, which has different significance in different products, could not be solved by evaporator design alone. Several methods for flavor enhancement in citrus concentrates to compensate for losses during evaporation were introduced.

Peleg and Mannheim (1970) stated that a typical process, which was described originally by Meizner (1940), involved taking freshly-extracted juice which was centrifuged to remove all but the finest solids before feeding the 'serum' to the evaporator. The removal of solids prevented excessive viscosity increase during evaporation which in turn could increase the residence time, reduce browning, and consequently the juice could be concentrated up to 60%. Bielig and Werner explained that the serum concentrate was then mixed with the proportional part of a separated pulp (the centrifuged pulp which remained untreated and still contained most of the aroma components) in an agitating tank and was homogenised.

Bielig and Werner claimed that volatiles has been carried out on a large industrial scale for apples, oranges, and pineapples. The method was described by Clarke as to remove the volatile flavor substances, either by pre-evaporation or by steam-stripping operations holding the condensate with or without fractionation, and then to recombine these substances with the concentrated liquid after further evaporation has been performed to the required final concentration. Werner stated that the amount of vapors to be evaporated depended on the type of fruit juice and ranged between 10 and 30% of the feed juice quantity. Normally the aroma recovery plant operates at atmospheric pressure. Degree of concentration (one litre aroma has been recovered from 100 litres of juice) of fruit aroma concentrates ranges between 100-200. In case of orange juice, the aroma was claimed by Bielig to increase 500 fold or more. Then the addition of aroma concentrate to the juice must be determined by a taste panel.

Robbins and Gresswell stated that the 'ester-recovery system' was also introduced to the evaporator plants, in which the first vapors to leave the juice were condensed and recovered. Unfortunately, because many of the low boiling substances escaped the condenser, and the volume of liquid recovered was so great, this system was of little practical use. Theyalso suggested that, as a compromise, processors could evaporate a proportion of their juice and then to blend the concentrate with straight juice with or without admixture of peel oil. This so-called 'cut-back' technique was used particularly with orange juice, an original sixfold concentrate might be reduced to fourfold strength with fresh juice before packing.

2.8 Storage and Stability of Juice Concentrates

Saravacos (1970) claimed that commercial orange juice concentrate was of over 40° Brix. Bielig and Werner stated that deterioration in the quality of concentrates was often found to be associated with an extremely high contamination of diacetyl-producing bacteria. High-temperature short-time evaporators were most common. Using higher temperature (60-80°C) of evaporation and extremely short holding time (30-60 sec) is a great advantage in modern juice concentration. Enzymes are inactivated and micro-organism contamination is remarkably reduced.

Trossler, Joslyn, and Marsh claimed that fruit juices concentrated to 72° Brix did not spoil readily at moderate temperature because most micro-organisms could not live in juice of such high concentration. However, molding might sometimes occur in nearly all concentration, and fermentation in some.

Borgstrom stated that the storage of concentrated orange juice established some problems. He claimed with reasonable certainty that unpasteurized concentrated orange juice would keep at $0^{\circ}F$ or below. This temperature would maintain good flavor and prevent clarification or gel formation. Exposure to $-15^{\circ}C$ or even $-12^{\circ}C$ for a short period of time would not affect the product seriously; but when held, only for short periods, at temperature of -9.5 to $6.7^{\circ}C$, a decline in quality and storage would take place even though the concentrate was consequently returned to storage at lower temperatures. Constant keeping at $-18^{\circ}C$ would maintain the original high quality of the concentrate both as to appearance, taste, and cloudiness after reconstitution. Nevertheless, Tressler et al. stated that in tests made by Irish (1925) concentrates had been stored experimentally at $30^{\circ}F$ for over a year without noticeable loss of color or flavor. It could be said that the ideal method of preserving concentrate was by cold storage.