# Chapter VII

# DISCUSSION

As far as concerned, the first intention of studying the inclined-film evaporator was to find out the new applicable evaporator for the food industries. Thailand has long been known as an agricultural country, plentiful of fruits are found available around the year. Most of fresh fruits are consumed in the country, some are export, and many are left. The study was then focused to the preservation of those fruits, but, according to the evaporation, fruit juices would be attended.

Fresh fruit juices of some kinds are consumed as well as fruit flesh. Among them, those well-known are juices from oranges, pineapples, tomatoes, guavas, and lemons. Marketed fruit juices are consumed in the form of syrup or beverage. They contain high percentage of sugar, artificial color, artificial flavor, and some preservatives. Most of them have low solid content and low vitamin C content, but they still stand very popular among the purchasers.

## 7.1 The Selection of Fruit Juice to be Studied

The selection of fruit juice to be studied was done with care consideration. The availability during the experimental period, the preparation process, the extraction of juice, and the cost per operation were also considered. The majority was to the citrus fruits for their popularity and the availability of extracting equipment. Further consideration was made to select the most proper species by the preceeding factors. Citrus reticulata Blanco was decided to be used though Citrus sinensis Lour was recommended(1,2)

The advantages were listed out as follows :

1. cheaper in cost,

2. more available in markets,

3. juice yield percentage is higher,

4. more convenience to extract with the available equipment,

5. higher percentage of solid content compared to Citrus sinensis, thus, the evaporation would consume less power,

6. color is more favorable

The disadvantages were also found as:

1. the separation of fruit pulp from the peel during the extraction which resulted in lower percentage of yield extracted juice, since the pressing and grinding had to be avoided to prevent the present of bitter taste.

2. the development of bitterness after extracting and processing, because the cutting of seeds at halving, the contaction between pulp and hairs with the juice during extraction, and the long standing at screening before pasteurization.

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

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

## 7.2 Some Technical Problems in Equipment Construction

The inclined-evaporator was first constructed in a $\frac{1}{4}$ oval shape provided longer evaporating path and corresponding with the change of viscosity of fruit juice during the evaporation. The equipment was tested and found that the heating plate was not level in the direction of width, but bent up to the center. This was due to the expansion and contraction of stainless sheet during the welding. The equipment was then reconstructed using a straight plate, having constant inclination of $60^{\circ}$ from the vertical line. The construction of elipse plate required more skilful technicians.

In order to regulate and maintain a constant feed rate to the evaporating chamber, a rotameter was then connected to the feed line. Unfortunately, the feed inlet valve which was a gate valve could not be used in adjusting the flow to a desired rate, and so attention must be taken at all time to maintain constant feed rate.

The use of gate valve as the feed inlet valve was not suitable as discussed previously. For better flow rate controlling, a glove valve should be used instead of the gate valve.

## 7.3 The Experimental Results

The present work had performed many experimental runs, but only the data and results of 7 runs were presented here. The others were rejected because of the confrontation to some difficulties and technical problems during the performance of the experiments. For examples, the sudden lacking of cooling water which increased the temperature in the evaporating chamber resulted in incrustation, foaming and burnt of juice, the operation was then shut down. Moreover, the vacuum applied during the evaporation was too low, the juice boiled at temperature exceed 50°C which resulted in the loss of volatiles and made the product unacceptable. So there was no use to carry on the experiments. However, the obtained experimental data revealed some significant points of view as followed:

1. According to the results of material balances around the evaporating chamber, the precision of the experimental data was sufficiently high. The data were consistent with the mass conservation law by having errors of less than few percents.(Tables 4,5 pp.66,67)

2. The present work was intended to study the effect of hot-water temperature on the performance of the evaporator. However, it was found that the hot-water temperature could not be varied as much as it should have been. The hot-water temperature for all experimental runs was quite constant. It changed only few degrees according to the change in flow rate which resulted in different outlet temperature and different heat transfer coefficient. The temperature can be varied significantly only by varying the inlet steam pressure. Unfortunately, the steam pressure used in the experiments could be controlled as low as 3 psi which was still too high. Hence, more accurate steam pressure gauge and pressure regulator should be used.

3. There was a range of proper feed rate which resulted in high evaporation ratio, when neglecting the hot-water temperature,

and this was found to correspond to the feed rate ranged between 0.26 - 0.31 liter/min. Higher feed rates resulted in lower evaporation ratios, because the residence time of fruit juice to be contacted with heated plate was short. Too low feed rates (less than 0.26 liter/min) resulted in the occurrance of dried spots on the heated plate, and this caused the burning out of the fruit juice and reduce the heat transfer area. Besides, higher feed rates yielded a larger amount with low concentration of concentrate juice. This necessitated the draining of the concentrate juice from the receiver tank, which had an insufficient capacity to hold such high amount of juice. The draining disturbed and lowered the vacuum, again the evaporating temperature was increased.

4. From the evaporation ratios, the value of e was found to depend on the feed rate. This can be explained that there was a proper condition of the feed rate and the plate temperature that the evaporation took place effectively. However, the temperature of hot-water did not vary so much for all experimental runs. It was expected that the maximum evaporation would have been obtained at a certain feed rate and a certain plate temperature. Unfortunately this optimum condition was not shown precisely by the present results. For the same feed rate with different hot--water flow rate, the evaporation ratios were quite different (as for run No. 1 and 7). This was either the effect of initial feed concentration or the hot plate temperature. Less solid content in the feed more evaporation occurred, since more water present in the feed provided better heat transfer during the evaporation.

5. As shown by the results listed in Table 9, the experimental results agreed reasonably well with the theoretical equation derived from the proposed model of process. The final concentrated juice flow rates per unit width which calculated from the equation were slightly less than those experimentally obtained for experiment no.1,2,3 and 7. This was because the actual evaporation of the system was not as effective as the theoretical one, less water was actually evaporated and a greater amount of concentrate juice with lower concentration was yielded. However, the results of experiment no.4,5,6 were opposite to those of the above few runs, and this was theoretically unsound. The disagreement of experimental results with the proposed equation might be caused by the cumulative effects of all sources of error and assumptions used in deriving the equation:

a. The measurement of operating time: The operating time for each experimental run was considered here as the time required since the opening of the feed valve, to let the juice flowing and evaporating, up to the closing of the feed valve. However, after the closing of the feed there was still some juice on the heated plate and evaporation processed for a short period of time, which could not be identified. Hence, the exact operating time required for evaporation could not be measured. Although the error of operating time was not much, it might be only few minutes, it could affect the results greatly. The values of $\Gamma_4$ , $q_4$ and their related values were all affected by the operating time. A trial of calculations showed that, for experiment NO.4, if the operating time changed by only one minute, i.e. from 2520 sec to 2580 sec, the measured $\Gamma_L$ which was equal to 0.0958 while the calculated $\Gamma_L$ was 0.1140 would change to 0.0936 and 0.1011 respectively.

b. The measurement of temperatures : It was found that the boiling temperature varied from point to point along the plate, and the range of variation was between 2 and 5°C. As the water boiled off, the solid content increased and so did the boiling temperature, and the heat transfer decreased. Thus the average temperature of Tv was determined by converting the vacuum-pressure reading to the corresponding boiling temperature. This value was found to be very close to the average of the temperatures on the heated plate. However, for an accurate result, thermocouples should be employed instead of thermometers.

c. The meter readings : The flow rate of hot water and the feed were not constant, so the manometer and the rotameter fluctuated. Hence, approximated average values were recorded.

d. The assumptions of constant physical properties : The density, viscosity, and thermal conductivity of fruit juice changed as increasing concentration along the plate of evaporation. However, the proposed model assumed that those values were constant. In the calculations, the arithmatic mean values of physical properties of the juice at the initial and final concentrations were used. Some errors might be possible, but the values did not vary so much within the range of concentrations concerned. Furthermore, the thermal conductivity of fruit juice was assumed to be the same as that of pure water at the same temperature. For precise analysis, additional investigation should be carried out to determine the thermal conductivity of fruit juice. The equation concerned should be derived and solved by numerical method since the $\rho$, $\mu$ and k are variables.

e. The heat loss : The heat balance were carried out by assuming that no heat loss around the unit. This was apparent that, in fact, there were heat losses from the feed tank, the evaporating chamber, the entrance to the condensers, and the concentrate-juice tanks. For evidence, the temperature of pasteurized juice dropped about 20-30°C during the period of pasteurization and transferring to the feed tank, and the temperature of concentrate-juice was lower than the boiling temperature.

6. The highest concentration ratios obtained do not exceed 3. This is too low in the economic point of view. To increase the ratio, the area of plate should be extended either the width or the length. The width extension seems to be more preferable in order to save the area. However, as the juice became more viscous the evaporation decreased, the film became thinner and might not cover all the plate. This should be solved by reconstructing the plate with varied slope, and the most suitable one would be in the form that correspond to the change of viscosity. The e-value calculated from the quantity of feed and product, and from their concentrations showed a little difference but agreeable. The precision of the Brix meter used was too low and also the balance used to weigh the quantity. The recorded values were not accurate enough. In addition, the concentration, which was determined by the Brix meter, was not calibrated at 20°C as instructed. The experiment was carried out at room temperature by using sugar

solution and the result indicated no significant difference whether to read at 20$^{o}$C or at room temperature. The further reading was then performed at room temperature for convenience.

7. The pH of juice before and after processing remained quite conatant,though the titratable acidity increased since the water content decreased. The acid content was expressed as citric acid because it is the main acid found in citrus fruits as reported by Woollen(1969). The titration using NaOH and phenolphthalein was quite rough because NaOH is a strong base while citric acid is a weak acid. Nevertheless,the results were reliable to those reported in the literature reviewed(Table 1.p.8).

8. The untitratable vitamin C content of concentrate juice might be possible because:

a. Vitamin C was destroyed during the pasteurization and evaporation process. It is a good reducing agent and may be easily oxidised to other forms (Jacobs 1959) which are untitratable.

b. The reagent used to titrate was not sensitive enough. Normally,the vitamin C content of fruit juice is determined by using 2,6-dichlorophenolindophenol which gives more accurate value but consumes more time.The solution used must be freshly prepared and standardised each time.The use of Iodine solution was more convenience and nevertheless showed reliable results within the average range for fresh fruit juice.(Table 1)

The poor content of vitamin C does not cause any serious problem,since for further processing the concentrate may be mixed

with fresh

fruit juice and gain vitamin C. Moreover the present or absent of vitamin C does not even regarded by the standard of Thai Industrial Standard Institute.

9.' The loss of volatile aroma after processing. This is the most critical problem, since it is the most impressive factor to the consumers ext to the color. The loss was due to:

a. The pre-heat treatment step: This process was necessary, it was to inactivate enzyme[1] activity, destroy or inhibit any original microorganisms load, and provide an increase in viscosity of fruit juice to make better flowing. The temperature used was rather high and the time was quite short. In fact, the change of aroma in this step was slightly noticeable and showed no intense off-flavor.

b. The evaporation process : Although the experiments were intended to be carried out under as high vacuum as possible on the purpose to reduce the boiling temperature, the vacuum was still too low. The edge of all glass windows, thermometer ports, and joints were all cemented by insoluble glue. The increase of about 150 mm.Hg vacuum was obtained. Further attempt was carried out by selecting the proper vacuum oil which would have yielded the higher vacuum within the evaporating chamber. If higher vacuum would be obtained, the boiling temperature would lower and the loss of volatiles would be reduced. According to Lowe and King, the loss of volatiles could be lowered by increasing the solid content. The study of adding some sugar and acid into the fruit juice before evaporating should be performed. This also hinted that the inclined evaporator should

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1 pectinesterase

consist of a varied-slope heated plate, and this would increase the evaporation ratio. The experimental results in Figure 16 showed that the lower the initial concentration the better was the evaporation.

The volatiles were found evidently to be trapped in the condensate and intensely in vacuum oil. This could also be further studied to fractionate or separate these volatiles and then recombine to the concentrate juice. All the wastage such as peel and pulp should be attended too, since they have high volatile and high pectin content respectively. (Wagner, et al. 1972)

10. The unfavorable odor due to the present of some metallic compounds within the concentrate juice: The juice, after extracting, screening, and pasteurizing, was stored in the feed tank, being flowed in the evaporating chamber and collected in the concentrate-juice tank. All these contacted parts were constructed with stainless steel. However, these units were entirely closed, and this caused some difficulties in cleaning. The deposited scales on these contacted parts might be dissolved during the evaporation, and this might cause some unfavorable odor. Some juice sacs were also left dried inside the evaporating chamber during the evaporation which caused worse heat transfer for the following run and initiated higher boiling point. For further study, the equipment should be reconstructed to provide some openings for cleaning, and these openings should be able to be tightly closed for sure of accommodating vacuum.

11. The keepability and color of concentrate juice: It was found that the concentrate still had low content of soluble solids thus it could not stand alone. Sodium metabisulfite of 300 ppm.

provided the preserve property at room temperature neglecting the concentration. The use of sodium metabisulfite resulted from its easier in dissolving in fruit juice and its anti browning property.(Wirada et al.1961). The color of higher concentrations (more than 25°Brix) changed to brownish orange while that of lower ones(less than 20°Brix) was still unnoticeable.This could be caused by the high temperature heat treatment during the pasteurization, the long standing and overheating in the evaporation and even the exposure to the light. (For chemistry details see Food Chemistry Texts under'browning reaction'). The storage of 6 weeks in home refrigerator showed satisfactory unchange in color,except the precipitation. This is quite agreeable with the literature (chapter 2 p.25) which stated that the ideal storage of concentrate juice is by keeping in a cold place.

12. The appearance of concentrate juice: It was observed that both the concentrates stored in refrigerator and at room temperature developed floc after a period of time and then the floc became to separate from the juice and precipitated. The causes might be:

a. Unsufficient heat treatment to inhibit enzyme pectinesterase activity:The temperature used in the experiments was lower than that recommended by Borgstrom. Then enzyme pectinesterase could break down the pectic substances into galacturonic acid or its polymers which was soluble. However, for this study the preheat treatment was required only at a temperature equal to or slightly higher than the boiling point within the evaporating chamber.

b. The extraction of juice: The extractor capacity was too small. The rate was about eight litre per hour so the natural pectic substances present in the fruit might be destroyed by enzyme pectinesterase at the minute of halving. That is,the loss of natural cloud occurred before the inactivation of enzyme.

c.The long standing after pasteurization prior evaporation provided the heat accommodation which might reactivate enzyme activity. Moreover,bacteria of some kinds could attack the juice at any time and resulted the precipitation.