CHAPTER V

DISCUSSIONS AND CONCLUSIONS

5.1 Discussions

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The drying rate curves presented in this experiement were all in the falling rate period, this confirmed that the initial water content of the tapioca chip was not so high, and the drying rate was controlled by the internal drying mechanism. That is the mass transfer rate at the surface of the chips was faster than the rate within the chip, or the molecular diffusion is the controlling factor.

From Figure 4.5 in part A, it showed clearly the shorter time required for the through-circulation drying over the solar drying which is considered an unreliable process, particularly during rainy seasons, since it depends upon solar radiation. It took about 9 to 12 hours to dry the Malaysian size chip to 10 percent water content on a cement floor. By air-through circulation method, the drying time for this case was reduced to only

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2 hours or about 20% of the solar-drying time. Efforts to develop this method are understandable if its advantages over solar-drying is considered. Among these advantages are: reduction in space requirement, reduction in labour requirement, independence of weather, better quality control and eliminating possibility of pollution problem. The investment in through-circulation drying method will concern the cost of fuel, power, equipment and maintenance. However, the artificial drying from this experiment may still be too expensive for a high-moisture, low-cost product like tapioca chips for animal feed. Its potential may lie in a combination with sun-drying. It is noted that chip sizes used industrially in Thailand have a little bit larger dimensions than the Malaysian chips. Efforts were made to obtain the Thai cutting machine but was unsuccessful due to the lack of financial support. However, this study of the Malaysian chip sizes should still be useful for further work.

Figure 4.1 and 4.6 to 4.9 showed clearly the influence of air flowrate on the drying. The effect of air flow rate on the drying rate at this temperature level is noted and could be explained as follows. When the air flow rate was increased, the rate of mass transfer of water from the tapioca surface to the bulk of drying gas increased as the mass transfer coefficient was increased with the degree of turbulence. However, it is believed that as the air flow rate is further increased, this effect would be reduced and at certain value the flow rate will play no important role and diffusion mechanism is the controller of the drying rate. Unfortunately, due to the capacity limit of the existing air compressors this higher air flow rate could not be achieved.

In through-circulation drying using the fixed bed column, one of the principal variables was the bed thickness which was expressed as a linear depth. It was impracticable to measure this accurately when the individual pieces were large and the bed loading was therefore used which was expressed as Kg. of bone-dry solid (Kg. B.D.S.)/m^2. of bed area.(5) In Figure 4.10 to 4.13, the higher bed loading used, the slower rate of drying was. This could be explained that when hot air flowed through the bed, some part of the heat would be spent for the evaporation of the water from the chips at the lower section. When the bed depth was higher, more heat was spent before it reached the upper part. In Figure 4.12 the bed loading did not show so pronounced effect as that of Figure 4.10. This was because the air flow rate in Figure 4.12 was higher which was almost adequate to decrease the nonuniform air movement inside the column and help to carry away the evaporated water from the bed.Moreover, the higher air flow rate would carry with it more sensible heat into the bed.

In Figure 4.14 to 4.17, the drying time was reduced with the increasing temperature. This was due to the increase in heat transfer by conduction and in mass transfer by diffusion in the chips as the temperature was raised. When surface evaporation occurs, there must be a movement of moisture (or diffusion) from the inside of the tapioca chip to the surface. As the temperature was raised the value of diffusion coefficient or diffusivity was increased which permitted this movement faster and resulted in high rate of drying.

Although, the using of high temperature of hot air can give the high rate of drying, the quality of the tapioca chips must be practically taken into consideration. Chirife and Cachero[5] reported that scorching of the tapioca chip occurred at 84°C and over. In some of this experiment the scorching of tapioca chips would start to occur at the temperature higher than 80°C. Scorching is commonly associated with overheating. If the degree of browning is not great, the off-colour may be the only noticeable effect, but when the change proceeds further the flavor and the rehydration capacity (for other kind of vegetables) may also be adversely affected.

Toh[4] showed that scorching was not only a function of temperature but it was also dependent on the moisture content and the time during which the tapioca chip was subjected to the temperature.

In Figure 4.18 to 4.21, chip thickness also showed an important effect on the drying. The thin chip would have the high drying rate.

As the thickness of the chip was the diffusion path for water to move from interior to the surface, the time of this movement was dependent on the length of the path. The thicker the chip was, the longer time the diffusion took. Especially, when diffusion controls, the rate of drying is inversely proportional to the square of the thickness as shown by the equation belows.[6]

$$\frac{-dW}{dt} = \frac{\pi^2}{2} - \frac{D^2}{S^2} \cdot W$$

When W = Average free moisture content at time t sec.

D = Diffusivity, $cm.^2/sec.$

S = One-half slab thickness, cm.

One phenomena that occurs in drying for most of the fruits and vegetables is the shrinkage of the body. This shrinkage causes the structural changes and also decreasing of transfer area. In this experiment, shrinkage began at water content of about 0.3 to 0.5 Kg water/Kg. dry solid. So at the final stage of this drying, the thickness of the chip would not be constant and gave some error in the diffusion mechanism study at the terminal period. However, the shrinkage which occurred in tapioca chip was still small when compared to those occurred in other kinds of vegetables.

In part C, the experimental results were analysed to obtain the effective diffusivity in the tapioca chip and the calculated value was found to increase with the temperature following the Arrhenius equation.

The calculated values of the diffusion coefficient of tapioca chip from run no. C - 5 and C - 6 were compared with those in potato slabs which were determined by Saravacos[7] and those in tapioca of different species determined by Chirife[3] as shown below:

Temperature °C	De of tapioca in this study cm^2/sec.	De of tapioca by Chirife cm^2/sec.	De of potato cm^2/sec.
55	3.74×10^{-6}	3.3×10^{-6}	2.58×10^{-6}
70	4.70×10^{-6}	-	6.36×10^{-6}
100	7.52×10^{-6}	8.6×10^{-6}	-

The values of diffusivity of tapioca (Manihot esculenta Crantz) found in this study were of comparable magnitude to those found by Chirife in Argentina (of species Manihot utilissima Pohl) It is noted that the rate of which the diffusivity of tapioca responsed to the temperature was slower than that of the diffusivity of potato. This might be due to the difference of the structure of tissue. The cell walls and other non-starch constituents of tapioca have a major influence on the transport of water through the tissue. However, the function of cell membrane and cell walls with respect to water transfer during drying is not known in detail.

Throughout this study it was assumed that water migrates within the tapioca chips by diffusion mechanism. This assumption is supported by the experimental evidence which consists in the exponential relationship between $\bar{E}$ ($\bar{W}$-We/Wo-We) and the drying time, and the Arrhenius type temperature dependence of calculated values of the effective diffusivity as shown in Figure 4.22 and 4.24.

The results from run no. B - 14, B - 15, B - 16 and B - 17 were plotted again in Figure 5.1 to show the effect of air temperature on drying time. The hot air temperature was varied in the range 60 - 90°C. It was mentioned in the preceding paragraph that the increase in temperature would reduce the drying time, but, however, the optimum operating condition should be obtained considering the effect of temperature on the physico-chemical characteristics of the dried product. From this figure, it is seen that at temperature above 80°C, the drying time would not be reduced so much as compared to that in lower temperature range. It is therefore recommended that drying should not be performed above 80°C.

The effect of air flow rate on the drying time is also shown graphically in Figure 5.2. The air flow rates used in this experiment ranged from about 1,000 - 2,000 Kg/hr.m^2. Up to a value of about G = 1,500 Kg/hr.m^2, the increase of air flow rate would reduce remarkably the drying time, but further increase was not so effective, since the drying time appeared to tend to a limit for an air flow rate greater than 2,000 Kg/hr.m^2. This can be explained by the reasons that at low air flow rates, the drying rate is controlled by a mixed mechanism the mass transfer at the solid-gas inter-phase and the internal diffusional mass transfer. When hot air flow rate is increased, the superficial mass transfer coefficient is also increased until for a given value, the superficial resistance is negligible compared to the internal resistance, and diffusion in the tapioca chip controls the over-all rate of drying.

The shape of the time versus bed loading curves for different materials is illustrated in Figure 5.3. It is clear that none of the curves would pass through the origin but would intercept the ordinate. Burgess(8) who studied hops called this time intercept the "minimum time." This was the time required for a single layer of the material to dry under the same air conditions in the drying. The curve for hops was linear, whereas the curve for seaweed was concave upward and for tapioca was concave down-ward. Chirife(5) studied the drying of tapioca grown in Argentina and his curve was shown comparatively with the curve from this experiment.

From the experiment of part B, the optimum operating condition may be selected which is an important factor in the design of the drying process. The consideration of the true optimum operating condition depends on several important factors, especially, the industrial economy.

Figure 4.10 is taken to show the consideration of optimum operating condition. The optimum operating condition considered here was based on the thermal efficiency basis. Although the drying time of run no. B - 7 (5-cm. bed depth) was the least, it gave small product output which was not desired in industrial way. Run no. B - 9 (15-cm. bed depth) took 1hr. longer than that of run no. B - 7, but it gave approximately twice of the output rate. This run might be more interesting. The thermal efficiency shows how much the process benefited the heat from hot air. This value was calculated and tabulated with other factors as shown below. The detail of calculation is shown in Appendix B.

Run No.	Bed Depth (cm.)	Bed Loading $Kg.B.D.S/m^2$	Drying Time min.	Output rate $Kg./hr.m^2$	Thermal Efficiency %
B - 7	5	9.1	102	5.3	19.8
B - 8	10	18.4	132	8.4	28.9
B - 9	15	24.5	150	9.8	38.2
B -10	20	38.7	220	10.5	35.8

Run no. B - 9 has the highest thermal efficiency (at 38.2%) and also high output rate. Considering all important factors, it can be noticed that run no. B - 9 should be the most suitable one.

5.2 Conclusions

From the results obtained, it was concluded that:

1. In all conditions investigated, drying rates were in the falling-rate period.

2. The falling rate period had 2 stages of different diffusional mechanisms, the second was slower than the first.

3. All variable (air temperature, air flow rate, bed depth and chip size) had important effects on the drying of tapioca chips. The drying rate was increased with the increasing air temperature and flow rate; but it was decreased with the increasing bed depth and chip thickness. Hot air temperature, clearly, had strongest effect on the drying rate. The choice of optimum working temperature depended on the quality of the dried product. The temperature should not be higher than about 80°C which was the limit for scorching.

4. The drying rate of tapioca by through-circulation drying was much higher than that of sun-drying.

5. The assumed diffusion mechanism was supported by the experimental evidence as previously mentioned.

6. The values of diffusivity of tapioca found in this study were of comparable magnitude to those found by Chirife in Argentina and was also found to increase with the temperature according to the Arrhenius equation.

5.3 Recommendations

It was finally recommended that:

1. Similar study should be made for chip size used industrially in Thailand, that is by using the Thai cutting machine.

2. Larger scale of through circulation drying should be attempted.

3. Economic balance should be made before making a decision to apply this artificial drying method on industrial purpose. However, this method may lie occasionally in a combination with sun-drying.

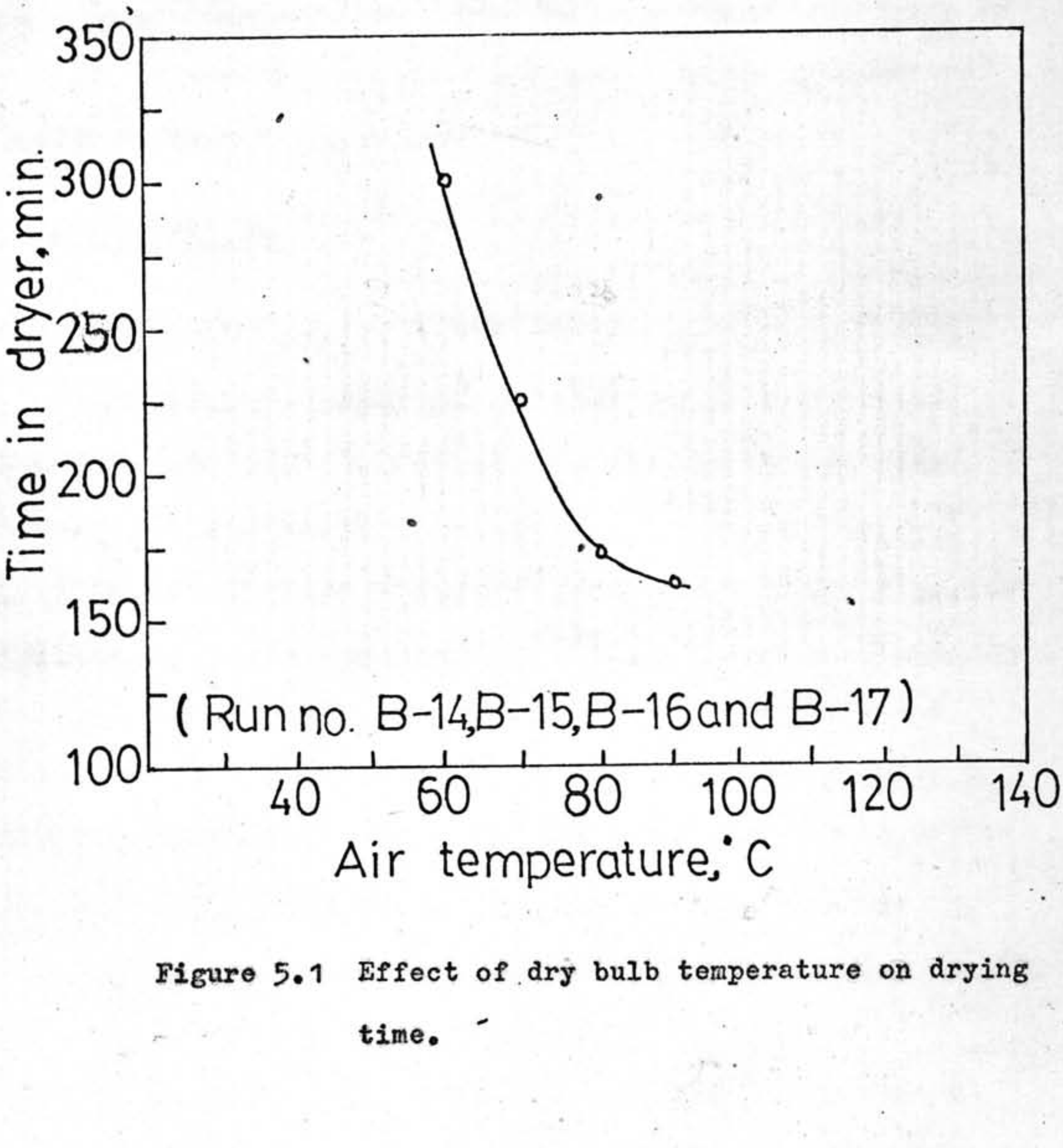

Figure 5.1 Effect of dry bulb temperature on drying time.

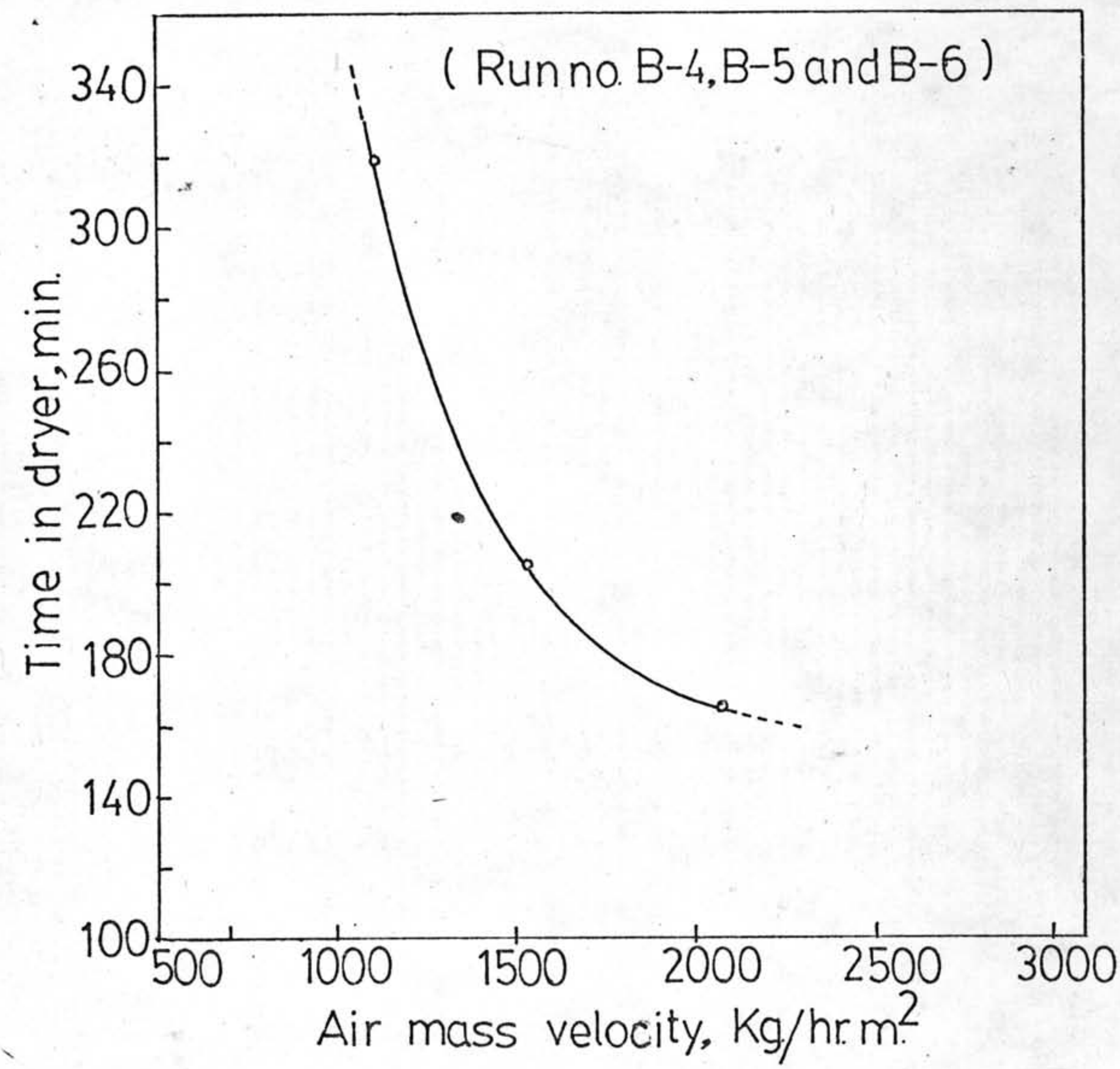

Figure 5.2 Drying time V.S. air mass velocity.

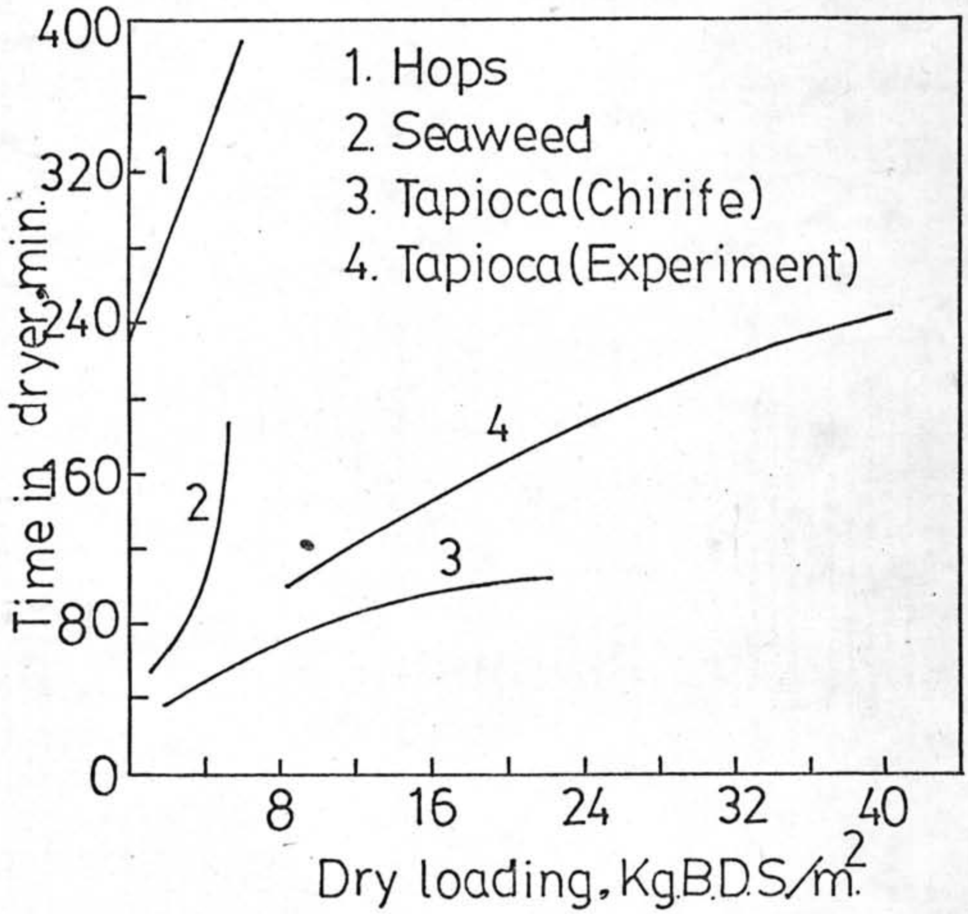

Figure 5.3 Effect of bed depth on drying time of vegetable material.