CHAPTER V

DISCUSSION AND CONCLUSIONS

DISCUSSION

5.1 Air Flow Rate

In Figure 4.14, at 76 °C and 2.2 mm gelatin thickness, the drying rates at 3.86 and 4.39 m/sec air flow rate, were the same and were greater than that at 2.16 m/sec. In Figure 4.15, at 98 °C, the same result was obtained, i.e., the drying rates at 3.84 and 4.39 m/sec air flow rate, were greater than those at 2.72 and 3.37 m/sec, and that at 3.84 m/sec was slightly greater than that at 4.39 m/sec.

It can be concluded that the drying rate is independent of the air flow rate of greater than 3.86 m/sec. Consequently, the resistance to mass transfer in the gas phase is negligible. Thus an air flow rate of 4.39 m/sec was used throughout the other drying experiments.

5.2 Effect of Temperature on Drying Rate

The plots in Figures 4.16 - 4.19 show clearly that the drying rate increased as the air temperature increased. For example, at a moisture content of 1.0 kg water/kg dry gelatin in Figure 4.16, the drying rate was 0.1900, 0.4200, 0.5600 and 0.6350 kg water/hr. m^2

at the air temperature of 32 °C, 57 °C, 76 °C and 98 °C respectively. This was due to the increase in heat transfer by conduction and convection, and in mass transfer by diffusion in the gelatin sol as the temperature was raised. When surface evaporation occurs, there must be a movement of moisture from the inside of the gelatin sol to the surface. As the temperature was raised the value of diffusion rate was increased which permitted this movement faster and resulted in higher rate of drying.

5.3 Drying Rate at Various Thickness of Sol

The plots in Figure 4.20 to 4.23 show that the greater the thickness of sol was, the slower the drying rate was. This could be explained that when hot air flowed pass the sol, some part of the heat would be spent for the evaporation of the water from the gelatin sol at the lower solution. When thickness of sol was higher, more heat was spent before it reached the upper part. The time of diffusion movement from interior to the surface, was dependent on the length of the path. The thicker the sol was, the longer time the diffusion took.

However, the difference in the drying rates of slabs of various thickness is small, especially at low temperatures, namely 32 °C and 57 °C. This may be because of the main resistance was at the hardening surface. At moisture content of less than 1 kg water/kg dry solid, the rate is almost independent of thickness.

5.4 Effect of Humidity on Drying Rate

The Figure 4.24 shows that in constant rate period, the drying rate of low humidity of air was higher than that of high humidity. But in diffusion rate period, it had the same drying rate. This was due to case hardening at the surface.

5.5 Thermal Degradation of Gelatin

Thermal degradation of gelatin can be determined by measuring the change in gelatin properties. The properties measured are the Bloom strength and the viscosity. The experiment revealed the Bloom strength of the dried product decreased as the temperature of drying increased. Figure 4.27 shows the relationship of Bloom strength and the drying temperature to be approximately linear in the temperature range of 30 ^{o}C to 98 ^{o}C. Gelatin is highly thermal degradable in the sol form. In the dried powder form when it was heated longer than 5 hours, the low Bloom strength was obtained. So heating time is an important factor as shown in Tables 4.2 and 4.3. Bloom strength of dried product decreased as the temperature increased. The increased temperature of drying lead to a reduction in the total number of hydrogen bonds.

Table 4.1 shows that drying temperature of 30 ^{o}C to 76 ^{o}C has no effect on the viscosity of the product. However, at high drying temperature of 98 ^{o}C the viscosity of the product decreases slightly. At a specified temperature and concentration, the viscosity of gelatin solution is a function of molecular length. Therefore, drying at 98^{o}C, the average length of molecules is probably slightly reduced.

The gelatin powder was heated at high temperature and various times, and no effect on the viscosity of the product was found.

5.6 Characteristic of gelatin drying

The plots between drying rate and water content showed clearly that they have constant rate period and falling rate period. When the gelatin surface behaves essentially as a free water surface, the gel temperature approximates the wet bulb temperature of drying air, which will be very much below the actual air temperature. This is the "constant rate" stage of the drying. When this phase is over and the falling rate drying period takes over, the temperature of the more concentrated, partially dried gel raises toward the drying air temperature and reaches it as drying ceases.

When free water is eliminated there is a tendency to form a sheath of partly dried gelatin at the surface (case hardening) and the drying rate decreases sharply.

Because of there is case hardening in the drying of gelatin, so control rate depends on the speed with which the water migrates from the interior of gel to the sheath of partly dried gelatin and the speed of the water moves within the sheath of partly dried gel. When case hardening occurs diffusivity of water can not be determined.

If the high temperature of the drying air is used, there is strong foaming of the gelatin solution, and the surface of gelatin product is not smooth. From experiment, the surface of gelatin product was smooth if air temperature was less than 32 $^{\circ}C$. At air temperature of 57 $^{\circ}C$, weak foaming occurred.

Browning reaction did not occur in the drying of gelatin, because the product had the same colour at different air temperature.

5.7 Diffusivity of water in gelatin gel at 25 ^{o}C

The drying rate curve of gelatin gel at 25 ^{o}C is shown in figure 4.25. Diffusivity may be obtained by the following equation.[6]

$$t = \frac{4 S^2}{\pi^2 D_v'} \ln \frac{8 (X_1 - X^*)}{\pi^2 (X - X^*)} \quad ....(5.1)$$

Where t = Drying time , sec

S = one-half slab thickness , cm

D_v' = Diffusivity of moisture through solid , cm^2/sec

X_1 = initial moisture content at start of drying when $t = 0$, kg water/kg dry solid

X^* = equilibrium moisture content , kg water/kg dry solid

X = moisture content at time t., kg water/kg dry solid

Plotting t versus $\ln \frac{8 (X_1 - X^*)}{\pi^2 (X - X^*)}$, a straight line was obtained in Appendix D and its slop is equal to 67.34 min. So that diffusivity of water in gelatin gel is equal to 1.214×10^{-6} cm^2/sec

5.8 Normalization of experimental Data for Design Application

It was found that the experimental data of rate of drying in Figures 4.16-4.19 could be normalised by defining

$$f = R / R_c \quad ......(5.2)$$

and

$$\Phi = (X - X^*) / (X_{cr} - X^*) \quad ......(5.3)$$

where f = relative drying rate

R = drying rate per unit exposed surface, kg/hr. m^2

R_c = constant drying rate , kg /hr. m^2

Φ = characteristic moisture content

X = average moisture content, kg water/kg dry solid

X_{cr} = critical - point moisture content, kg water/kg dry soli

X^* = equilibrium - moisture content, kg water/kg dry solid

The results of the plots of f versus Φ is presented in Figure 5.1. This is a very useful result, since only this figure is required to characterize the drying of gelatin sol. Use of Figure 5.1 in design is discussed in section 5.9.2.

It is evident that, in Figure 5.1,

$$\Phi \geqslant 1 \quad , \quad f = 1$$
$$0 \leqslant \Phi \leqslant 1 \qquad 0 \leqslant f \leqslant 1 \qquad \ldots.(5.4)$$

5.9 Application

The result of this work will be helpful in drying process design of gelatin. Two major considerations in the design are:

(a) property and appearance of the product desired.

(b) economics of drying.

5.9.1 Operating conditions

Property and appearance of the product depends on the operating conditions. Drying of gelatin sol above 50 ^oC will cause foam formation. The higher the temperature tne more foam are formed.

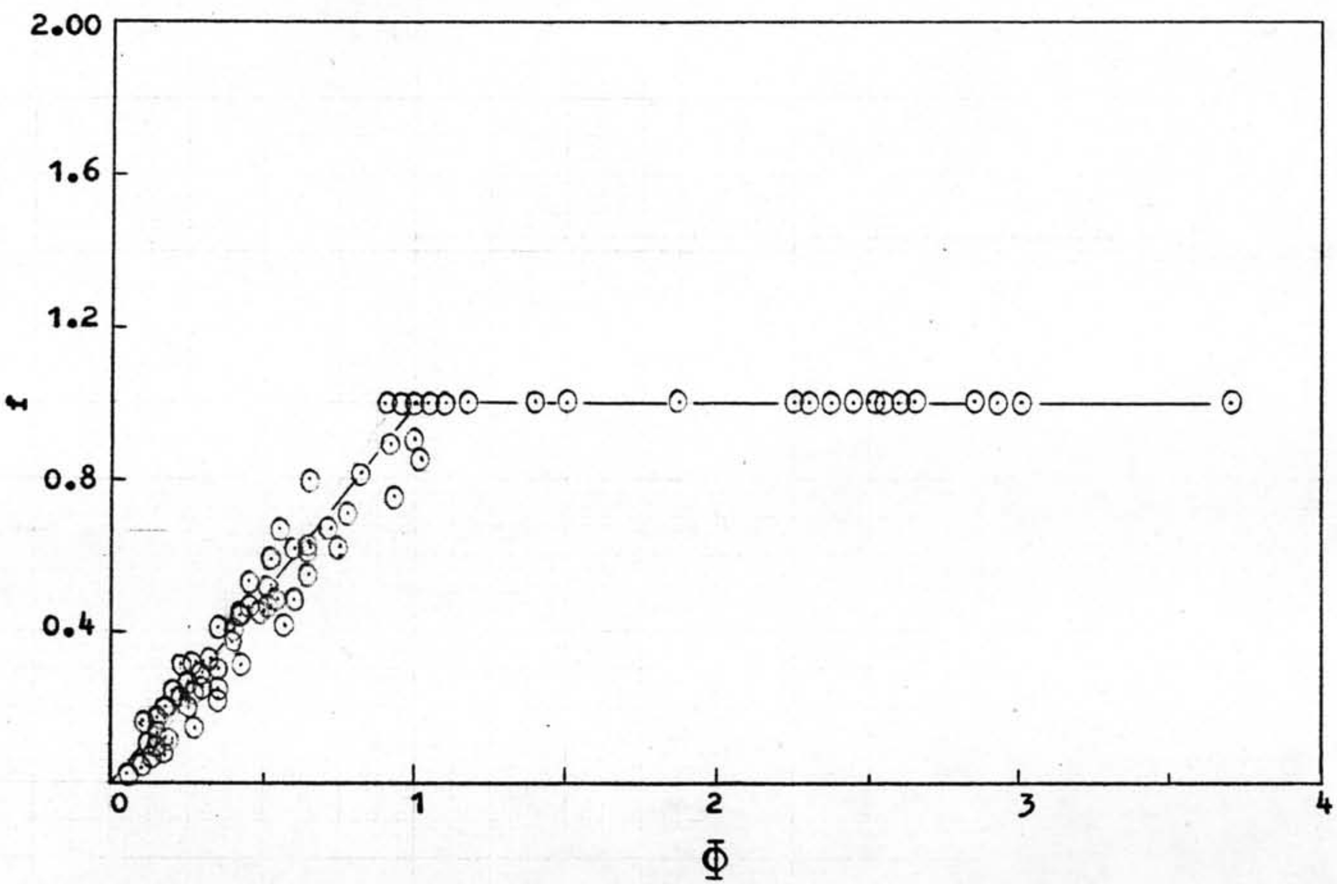

Figure 5.1 Normalized curve

At high termperature, around 90 ^{o}C, tear and scratch at the surface will be apparent. Gel strength decreased as drying temperature increased as shown in Figure 4.27.

Appearance depends on the drying rate. The other parameter which influence the drying rate, besides temperature is humidity. However; by the experiment (Figure 4.24), tne rate is not sensitive to change in humidity. Good appearance may probably be obtained at humidity closed to saturation at which tne rate will be very slow and thus uneconomical. Good appearance can certainly be obtained from dry gelatin gel at low temperature. The rate of drying may be increased by lowering the pressure. This operating condition may not be economical in a tropical country.

If appearance is not the major requirement drying gelatin sol at high temperature is probably the most economical. Another advantage of high temperature drying is that the bacteria growth can be eliminated.

5.9.2 Drying Time

Drying time is a major factor in designing a dryer and effecting the economic. One may use values of the reciprocal rate ($d\theta/d\Phi$) to estimate drying times, since

$$t = \int_{\Phi_0}^{\Phi_t} \frac{d\theta}{d\Phi} \cdot d\Phi \qquad \text{....(5.5)}$$

The value of $d\theta/d\Phi$ is found from the absolute rate R in the following way :

$$R = -\frac{d}{d\theta}(\rho_s x/a) \qquad \text{....(5.6)}$$

Where a is the surface area of the drying gelatin per unit volume and ρ_s is the bulk density of the bone-dry gelatin. From the definition of the characteristic moisture content Φ in Equation 5.3 if follow that

$$\frac{d\Phi}{d\theta} = \frac{1}{(X_{cr}-X^*)} \cdot \frac{dX}{d\theta} \qquad \text{....(5.7)}$$

so that from Equations 5.6 and 5.7

$$\frac{d\theta}{d\Phi} = \frac{-\rho_s\ (X_{cr} - X^*)}{aR} \qquad \text{....(5.8)}$$

Substituion of this expression for $\frac{d\theta}{d\Phi}$ into Equation 5.5 yields tne working relationship

$$t = \frac{-\rho_s(X_{cr} - X^*)}{a} \int_{\Phi_0}^{\Phi_t} \frac{d\Phi}{R} \qquad \text{....(5.9)}$$

$$R = f\ K_0\ \phi\ (Y_W - Y_G) \qquad \text{....(5.10)}$$

Where f = a dimensionless of the moisture content as defined in Figure 5.1. It takes account of the thermopnysical properties of the gelatin being dried.

K_o = mass transfer coefficient characterising the operating of tne drying equipment.

$\phi\ (Y_W-Y_G)$ = the humidity conditions

ϕ = humidity potential coefficient

Y_W = wet - bulb humidity.

Y_G = bulb - gas humidity.

The integrand in Equation 5.9 may be evaluated numerically or graphically. Figure 5.1, 5.2 and 5.3 the values of f, X^* and X_{cr} respectively.

CONCLUSIONS

The result of the experiment was concluded as follows :

(1) Case hardening occurred in the gelatin sol drying.

(2) Drying rate curve of gelatin sol consisted of constant rate period and one falling rate period.

(3) The drying rate increased as the air flow rate increased, but when the air flow rate was greater than 3.86 m/sec, the drying rate was independent of air flow rate.

(4) Temperature had an important effect on the drying rate. The drying rate increased as the air temperature increased.

(5) The thickness of sols had small effect on the drying rate.

(6) Only in the constant rate period, the drying rate depended on air humidities, the drying rate of low humidity of air was higher than that of high humidity.

(7) Bloom strength of gelatin decreased as the temperature of drying increased.

(8) Diffusivity of water in gelatin gel at 25 ^{o}C was calculated to be 1.214 X 10^{-6} cm^2/sec.

(9) All of the experimental data could be normalized to give a single characteristic drying rate curve. This result makes design calculation more convenient.

(10) Equilibrium moisture content and critical moisture content were determined.

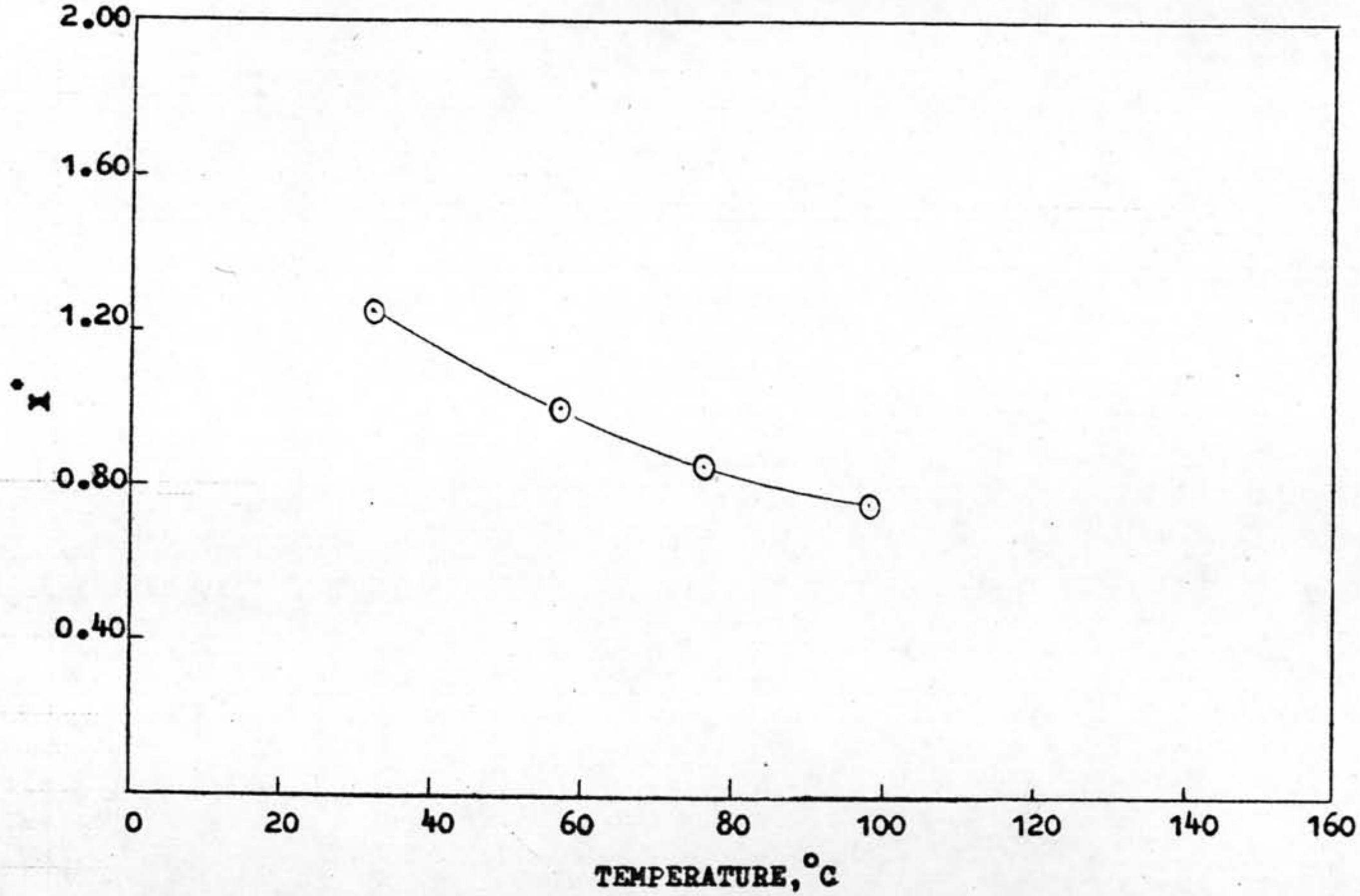

Figure 5.2 X^* vs. Temperature at 0.028 kg water/kg dry air

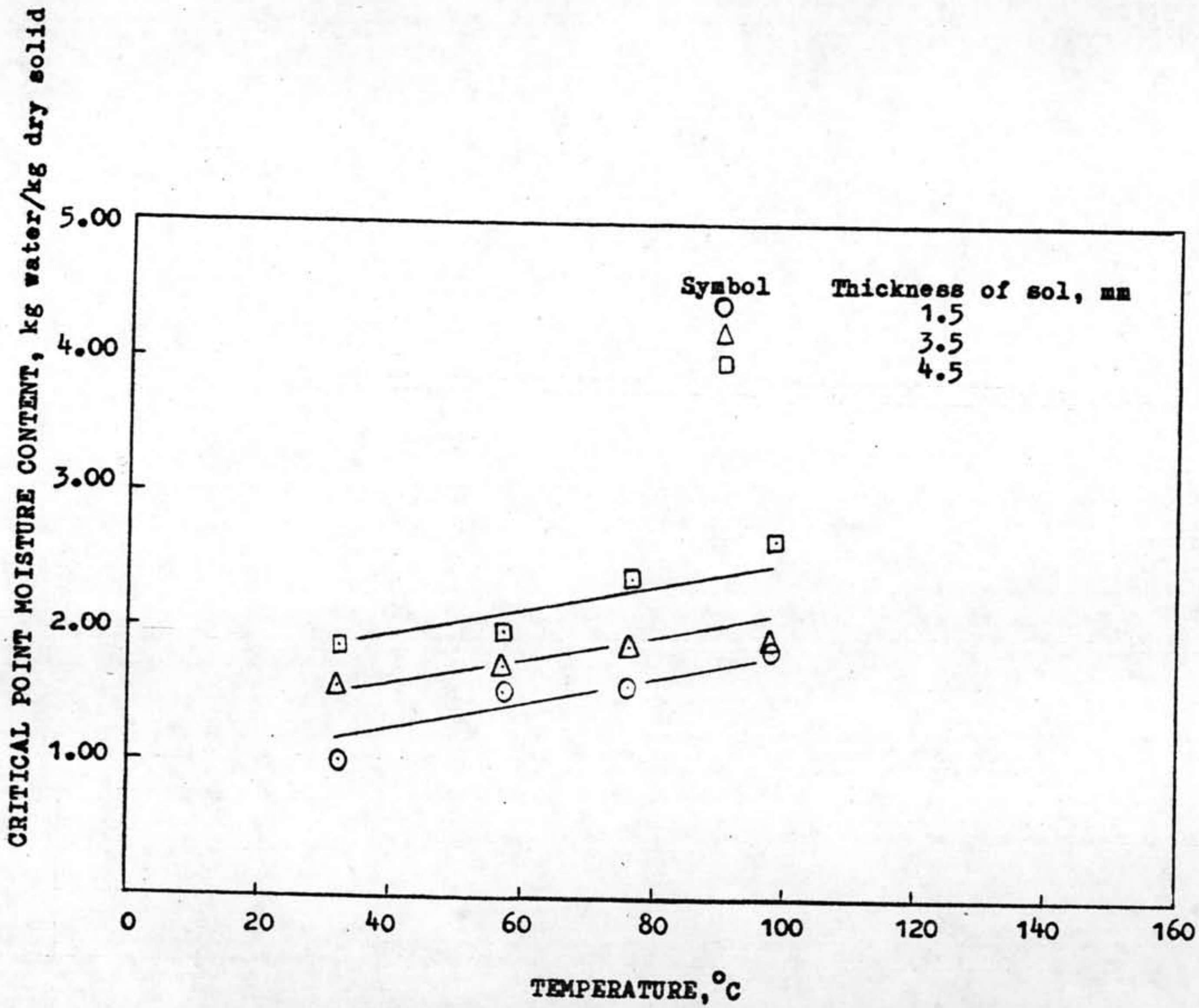

Figure 5.3 Critical point moisture content vs. Temperature at various thickness of sol