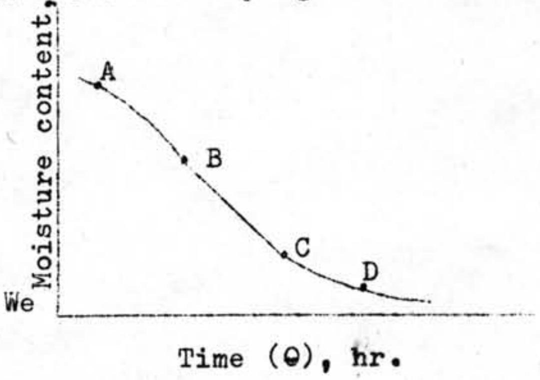
CHAPTER II.

LITERATURE REVIEW

2.1 General Drying Behavior

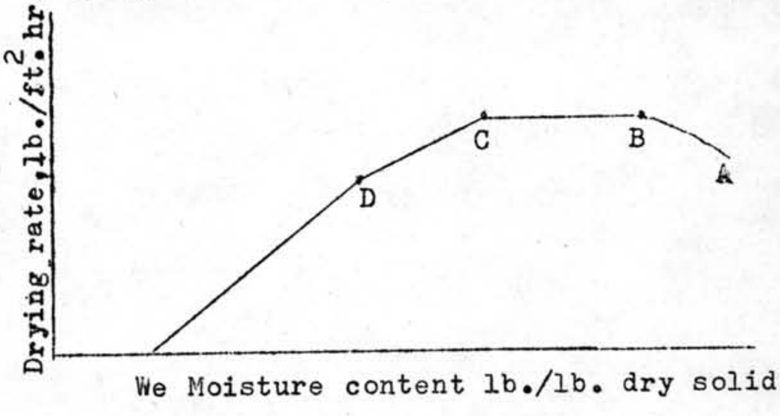
In drying a wet solid with a gas of fixed temperature and humidity, one general pattern of behavior always appears. Immediately after contact between the sample and the drying medium, the solid temperature adjusts until it reaches a steady state. The solid temperature and the rate of drying may increase or decrease to reach the steady-state condition. At steady state, a temperature probe would find the temperature of the wet-solid surface to be the wet-bulb temperature of the drying medium. Temperature within the drying solid would also tend to equal the wet-bulb temperature of the gas, but here agreement would be imperfect because of lag in movement of mass and heat. Once these stock temperatures reach the wet-bulb temperature of the gas, they are found to be quite stable, and the drying rate also remains constant. This is the so-called *constant-rate drying period*. The period ends when the solid reaches the *critical moisture content*. Beyond this point, the surface temperature rises, and the drying rate falls off rapidly. The *falling-rate period* may take a far longer time than the constant-rate period eventhough the moisture removal may be much less. The drying rate approaches zero at some <u>equilibrium moisture content</u> which is the lowest moisture content obtainable with this solid under the drying condition used. Fig. 2.1 and 2.2 show typical drying curves, one on a moisture-content versus time basis and the other on a rate of drying versus moisture content basis.

Fig 2.1



The moisture content versus time plot (Fig 2.1) is the form in which drying test data might be obtained. Fig 2.2, the rate of drying versus moisture content plot, is much more descriptive of the drying process. However, it is obtained by differentiating data in the form of Fig 2.1 and thus is subject to considerable scattering of data and resulting uncertainty.

Fig. 2.2



These typical drying curves are related to the mechanism by which drying occurs. The drying period represented by segment AB of the curves of Fig.2.1 and 2.2 is the unsteady-state period during which the solid temperature reaches its steady-state value. Although the shape shown is typical, almost any shape is possible, and AB may occur at decreasing rate as well as the increasing rate shown. During the constant rate period, segment BC of the drying curves of Fig.2.1 and 2.2, the entire exposed surface is saturated with water. Drying proceeds as from a pool of liquid film extends may increase mass and heat transfer coefficients, but this effect has not been firmly established. The surface temperature reaches the wet-bulb temperature as would be expected. The constant-rate drying regime continues with the mass that is transfered from the surface continuously replaced by movement of liquid from the interior of the stock. The mechamism of liquid movement and consequently the rate of this movement vary markedly with the structure of the solid itself. With solid having relatively large open void spaces, the movement is likely to be controlled by surface tension and gravity forces within the solid. With solid of fibrous or amorphous structure, liquid movement is by diffusion through the solid. Since the diffusion rates are much slower than the flow by gravity and capillarity, solids in which diffusion controls the liquid movement are likely to have short constant-rate periods, or even to dry without a measurable constant-rate period. At point C, the moisture content of the solid is barely adequate to supply the entire surface.

During the drying period between point Cand D of Fig 2.2, called the "first falling-rate period" the surface becomes more and more depleted in liquid because the rate of liquid movement to the surface is slower than the rate of mass tranfer from the surface, until at point D there is no significant area of liquid saturated surface. The part of the surface that is saturated dries by convective transfer of heat from and of mass to the drying gas stream. Vapor from lower levels in the sample diffuses to the part of the surface that is not saturated and then continues its diffusion into the gas stream. This mechanism is very slow compared to the convective transfer from the saturated surface.

At moisture contents lower than that at point D of Fig.2.2, all evaporation occurs from the interior of the solid. As the moisture continues to fall, the path for diffusion of heat and mass grows longer, and eventually the concentration potential decreases until at We, the equilibrium moisture content is reached when the vapor pressure over the solid is equal to the partial pressure of vapor in the incoming drying gas. This period is called the "second falling-rate period."(2)

2.2 Moisture Movement-Diffusion Mechanism

It will be assumed that Fick's law is applicable to the movement of water in tapioca root; thus, for a rectangular parallelepipede,

$$\frac{\delta C}{\delta \theta} = D_x \frac{\delta^2 C}{\delta x^2} + D_y \frac{\delta^2 C}{\delta y^2} + D_z \frac{\delta^2 C}{\delta z^2} \text{ ------------------} (2.1)$$

Where D_x, D_y, D_z represent the diffusion coefficients along rectangular axes x, y, z, respectively.

If the medium is isotropic,

$$D_x = D_y = D_z = De \text{ ------------------------------} (2.2)$$

De being the effective diffusion coefficient. For unidirectional diffusion (i.e., infinite slab) eq. (2.1) becomes,

$$\frac{\delta C}{\delta \theta} = De \frac{\delta^2 C}{\delta x^2} \text{ ------------------------------} (2.3)$$

Sherwood (1929) solved eq. (2.3) assuming:

1) the initial moisture distribution is uniform.

2) the diffusivity is constant.

3) the resistance to moisture removal from the surface is negligible compared to the resistance to internal diffusion.

Under these assumptions, eq.(2.3) can be integrated. The result may be written:

$$(\overline{W} - We)/(Wo - We) = \frac{8}{\pi^2}\left[e^{-De\theta\,(\pi/2a)^2} + \frac{1}{9}e^{-9De\theta\,(\pi/2a)^2} + \frac{1}{25}e^{-25De\theta\,(\pi/2a)^2} + \ldots\ldots\right] \ldots\ldots\ldots (2.4)$$

Where

Wo = initial moisture content

We = final equilibrium moisture content

$\overline{W}$ = average moisture content at the time θ

De = effective diffusivity, cm.^{2}/sec.

a = one-half slab thickness, cm.

θ = time, sec.

All moisture contents are in Kg. of water per Kg. of bone-dry solid. The accuracy of the diffusion theory for drying suffers from the fact that the diffusivity usually is not constant but varies with moisture content. It is especially sensitive to shrinkage. The value of De is less at small moisture contents than at large and may be very small near the drying surface.

In practice, an average value of De, established experimentally on the material to be dried, is used.

For long drying time eq.(2.4) simplifies to give:

$$(\overline{W} - We)/(Wo - We) = \frac{8}{\pi^2}\, e^{-De\theta\,(\pi/2a)^2} \quad \ldots\ldots\ldots\ldots(2.5)$$

When eq. (2.5) is plotted on semilogarithmic paper, a straight line is obtained. Eq. (2.5) holds only for a solid slab where thickness is small relative to the other dimensions.(3)

2.3 General Drying Method of Tapioca.

2.3.1 Sun-drying

The common practice in Thailand is to produce the chips early in the morning, from about 07.00 to 10.00 A.M. The fresh chips are distributed on the drying floor and then spread out manually with the use of shovels. The spread-out chips are turned over every 1 - 2 hr. with the use of rakes.

At the end of the day or during rainy weather the chips are heaped into mounds, which are sheltered under portable roofs made of corrugated iron on wooden frames.

A small proportion of the chips, particularly the small particles and powder, remain on the drying floor. These are collected by workers with the use of various types of brooms, wooden boards, and wheel barrows.

Since sun-drying is entirely dependent on the weather, the duration of drying and chips quality vary considerably. The time of drying and the chip quality are also dependent on the chip size. In Malaysia, where chips are small, drying is completed to about 15% moisture content in 1.5 days. This would take about 3 days in Thailand where the chips are longer. In Indonesia, the dried roots still contain about 25% moisture after about 1 week drying.(4)

Among the energy losses during sun-drying, the following could be the most important; incomplate absorption and reradiation to the atmosphere, heat transfer by convection to the atmosphere and heat transfer by conduction through the drying floor to the ground.

2.3.2 Artificial heat drying

There are a large number of dryers that can be used for tapioca products. These may be roughly classified into five groups. A brief discussion of each group and its possibilities for drying chips follows.

a) Static-bed dryers

All the commercial batch crop dryers, i.e., storage, bin, tray, and through-circulation dryers, that have been used for wheat, rice, coffee, and other similar agricultural products, may be included in this group.

One big advantage of the static-bed system is its simplicity. Its consists of a fan and its drive, and oil burner and bins, trays, or any other container with perforated bottom through which the heated air may be passed. Against this advantage, however, several disadvantages may be mentioned, some of which are inherent in a batch system, such as low heat efficiency, variable moisture content in a batch, and low throughput.

Overall rate of drying can be increased by using smaller size chips accompanied by sufficient supply of heat by blowing larger quantities of hot air through the bed. As the size of chips decreases, however, the amount of air that can be passed through the bed decreases for the same bed depth and the same pressure drop. In other words, just to maintain the same airflow rate through the same bed depth, higher pressure drop across the bed must be allowed for, which means increase in power consumption to drive the fan. It can be seen that there is need for the selection of optimum operating conditions, which include beddepth, chip size, air flow rate as well as air temperature.

Although these crop dryers have been used successfully for wheat, rice, coffee, bean, etc, the system may still be too expensive for a high-moisture low-cost product like chips for animal feed. Its potential may lie in a combination with sun-drying.

b) Moving-bed dryers

This system is similar to the static-bed except that the bed is moving either continuously or intermittently from one end to another. This allows continuous feeding of wet material from one end and continuous withdrawal of dried products from the other.

The bed movement is achieved by having, among others:

1) the bed of materials resting on a perforated moving band, as in the horizontal pellet coolers;

2) the bed continuously moved by chain conveyors resting on a stationary perforated or louvered floor;

3) the layer of material moving by gravity along a sloping perforated floor or cascading down a louvered bed.

4) a column of the materials moving downward as the dried product is continuously removed from the bottom of the column as in a vertical pellet cooler.

Some of the above techniques may be suitable only for free-flowing materials like grains. Their suitability for a particular type of cassava chips must always be experimentally ascertained before application.

Advantages of the moving-bed over static-bed systems are

1) uniform moisture content of dried products
2) better control over temperature and moisture content
3) higher heat efficiency possible.

Although the heat efficiency may be higher than that of the static-bed dryer, the fuel consumption may still be too expensive for chips production for feed purposes. As with the static-bed dryers the potential of this system may still be in its combination with sun-drying. Their economics, however, must be determined for each particular location, where wages, fuel cost, and sunshine are taken into consideration.

c) Rotary dryers

In a rotary drying system, the materials is fed from one end of a rotating cylinder with longitudinal lifters, and the dried products withdrawn from the other end. The drying gas may enter the cylinder either from the feed (parallel system) or from the dry product ends (counter current system). As the cylinder rotates, the material is lifted and dropped periodically through the passing gas.

After each lift, the material is moved forward with the help of gas blowing on it in the case of light materials and parallel flow system, or with the help of a slope in the cylinder.

The volume of gas that can be passed through a rotary dryer per unit weight of material being dried is much more than in the static or moving-bed dryers, and it is relatively independent of the particle size.

This system was tried for tapioca chips in Malaysia but without success. The gas temperature used was between 500 and 600°C. It is suspected that the high initial temperature produces case hardening on the chip, which results in sudden surface temperature increase and scorching.

One possible solution to the above problem would be the use of mechanically dewatered ground tapioca. It is hoped that the smaller particles and the lower initial moisture content will minimize case hardening and scorching. A preliminary test at the University of Malaya (1974) shows that ground tapioca can be dewatered to 42% moisture content in a hydraulic press at a pressure of 2500 psi. The cake obtained could be easily crumbled. Another advantage of the partial dewatering method is the reduction of fuel requirements,as the amount of water to be evaporated is reduced from about 60 to 20 Kg. of water per 100 Kg. of fresh roots. This advantage, however, must be weighed against the cost of mechanical dewatering and the recovery of solid, mainly starch from the pressed-out water.

d) Fluidized-bed dryer

When gas is passed through a fixed bed of particles, the pressure drop increases as the gas flow increases. For small particles, the amount of gas that can be passed is very limited. However, if the particles are sufficiently small the passage of gas at a high flow rate creates turbulent motion in the bed. The bed behaves like fluid, and is known as the fluidized bed. A reasonably wide range of particle size is prefered for fluidization.

The use of this technique in drying gives many advantages. The most important are high rate of drying due to rapid mixing, easy temperature control throughout the bed, absence of moving part in the dryer, compact size, and the low heat losses.

The partial dried ground tapioca could be crumbled into loose particles, which indicates that it may be suitable for fluidized-bed drying.

e) Pneumatic dryers

If the gas flow is further increased in the fluidized bed, individual particles will eventually be carried upward. If sufficient length of passage is provided, wet particle could be dried in hot gas, as the particle are being suspended and pneumatically transported by the gas.

This technique is used in the drying of tapioca starch. The partially dried ground tapioca, although of larger particle size than the starch, may be sufficiently fine for pneumatic drying.