CHAPER V

DISCUSSIONS AND CONCLUSIONS

5.1 Discussions

All drying rate curves obtained in this study showed no constant drying rate period. That is, all the drying of Jujube, Sapata, Grape and Stat-Gooseberry took place in the falling rate period.

5.1.1 Effect of Hot Air Temperature

Figures 4.8, 4.9, 4.17, 4.18, 4.24 and 4.25 show that the drying rate generally increased with air temperature. This was attributed to the increase in temperature gradient, the driving force for heat transfer between the hot air and the drying material. Simularly, the resulting increase in vapor pressure gradient, due to decrease in relative humidity, caused the mass transfer rate to rise and to a new dynamic equilibrium.

If the air temperatures were raised to high and/or the mass transfer rate were slow in comparison with the heat transfer rate, then sever overheating would occur, resulting in scorching of the product. Scorching is generally not only a function of the drying temperature but also the moisture content and drying time.

On the other hand, the effect of drying temperature on the product quality must also be taken into consideration. Sweetman (50) reported that the drying temperature should not be above 175-185^{o}F (79^{o}c-85^{o}c) for fruits and vegetables. Ponting and Mc.Bean(11) reported that grapes showed some browning when dried above 170^{o}F. For the above reason, all drying experiments in this study were carried out below 80^{o}c.

5.1.2 Effect of Bed Height

Figures 4.7 and 4.12 reveal that the drying rate was not affected by the slight change in bed height in this study. This was because the volume of drying air was quite high and the air properties remained essentially constant throughout the bed height.

5.1.3 Effect of Air Velocity

An increase in air velocity will cause a reduction in the boundary film thickness around the drying material, resulting in a decrease in film resistances to mass and heat transfer between the air current and the material surface. The overall heat and mass transfer resistances respectively are, however, the sum of film heat and mass transfer resistances, interface (i.e.material skin) resistances and material inner resistances. The skin resistances will depend not only on the type of skin material (porous, semipermeable or impermeable) but also on the skin thickness. The inner resistances are not only characteristic of the type of material but on the prevailing drying mechanism, which in turn are influenced by the shape and size of drying material and the imposed drying conditions. For example, a dried-out zone may or may not appear under the material skin, and the moisture content may move through the dried out zone in the form of water or vapor. Therefore, the overall effect of air velocity will depend on the relative magnitudes of film, skin and inner resistances

Figures 4.10 and 4.11 show an example in which the drying rate did not increase despite an increase in air velocity. This implied that the rate of inner moisture movement to and through the material surface was the rate controlling step. That is the film resistance to mass transfer between the material surface and the air current was negligible, and thus the moisture content at the surface was essentially in equilibrium with the air humidity. Therfore, the air velocity caused negligible effect on the drying rate, which was essentially determined by the humidity gradient in this case.

The effect of air velocity on the drying rate of Sapota is shown in Figure 4.20. Initially, the drying rate at high air velocity was a little slower than that at a low air velocity. This might be due to the difference in Sapota species of Figure 4.35 and 4.36.

Figures 4.19 and 4.26 show the case in which increased with air velocity. This implied that the magnitude of film resistance was larger than or of the same magnitudes as the skin and inner resistances.

The effect of air velocity on the film heat transfer coefficient can estimated by (52)

$$h \propto G^{0.37} \tag{5.2}$$

5.1.4 Effect of Air Humidity

Figures 4.10 and 4.11 show the case in which the drying rate at a high air velocity could be less than that at a lower velocity. An explanation of this has already been given and is not repeated here.

Figures 4.19 and 4.23 show the case in which air humidity had negligible effect on the drying rate of Sapota and Grape.

5.1.5 Effect of Pre-Treatment

Jujube and grape have a thin waxy coat on the outer surface. This waxy coat presents a great resistance to moisture movement during drying. So their drying rate is usually mass-transfer controlled. Therefore, in conventional drying of grape and jujube, the waxy coat (cuticle layer) is generally removed before drying.

The effect of pre-treatment by dipping is strong if it can nearly duplicate the effect of skin removal. Martin (53) found that the drying rate of grape was controlled by the rate of water movement through the waxy cuticle. Ponting (11) determined the drying time required to cause a 70 % weight loss for grapes with and without dipping. At a drying temperature of 150^{o}F, it took about 30 hrs without dipping but only 15 hrs with dipping in 1 % ethyl oleate solution. Ponting(11) also found that a dipping time from 0 seconds to 3 minutes yield approximately the same drying rate.

5.1.6 Equilibrium Moisture Content

By definition, the equilibrium moisture content of a dried product is the moisture content of the material after having been exposed to a particular drying environment for an infinitely long period of time. Table 4.4 shows that the equilbrium moisture content was dependent upon the relative humidity and temperature of the hot air as well as upon the type of materials. Brooker (57) showed that the variation in equilibrium moisture content value is casued by a difference in the material vaiety, the material maturity and material history.

5.1.7 Type of Materials

Figure 4.29 shows the drying characteristics of various agricultural materials under the same air temperature and velocity. The drying characteristics depend on the nature of water contined within the material, which in turn depend on the characteristic of the inner material. However, the function of cell membranes and cell walls with respect to water transfer during drying is not known in details.

5.1.8 Classification of Materials according to Drying Characteristics

This study suggest that classification of drying materials may be made as follows:

1. Film-Resistance Dominant Materials

Film resistance could become dominant if the air velocity is very slow or the the size of drying material is very small. To increase the drying rate, we might

a. Increase the air temperature, that is, the temperature gradient, if the film heat transfer resistance is more limiting than the film mass transfer resistance.

b. Decrease the air humidity if the converse of a. is true.

c. Increase the air velocity.

c. is the most effective way to reduce both film resistances simultaneously, since it directly decreases the thickness of the boundary film layer.

2. Skin-Resistance Dominant Materials

Skin resistances could become dominant if the material surface is impermeable or only slightly permeable to moisture. In this case, skin mass transfer resistance would generally be more limiting than skin heat transfer resistance, and most effective way to increase drying rate would be to pre-treat the surface, for example, by dipping in a caustic soda solution. Otherwise, the skin might be peeled or ruptured mechanically. Sample of skin-resistance dominant materials in this study is grape. The drying rate of grape was controlled by the rate of water movement through the waxy cuticle.

3. Inner-Resistance Dominant Materials

Depending on the type of inner materials and the imposed drying conditions, inner resistances could become dominant. For example, if the inner materials are composed of small cells that hardly allow water to permeate their cell walls, or if severe drying conditions are imposed, resulting in a completely dry zone or hard shell around the drying material, then inner resistances may dominate. On the other hand, a material that shrinks rapidly during drying is seldom inner-resistance dominant.

A most effective way to reduce inner resistances is the reduce the size by slicing, pulverizing, etc. Increasing drying temperature or decreasing inlet air humidity would be only partially effective, whereas increasing air velocity would be ineffective.

4. Materials with Comparable Resistances

In many cases, two or more of the film, skin and inner resistances are, more or less, of the same magnitude. In this case, the most effective way to enhance drying rate would be to choose and manipulate the factor that simultaneously decreases the larger resistances. For example, slicing would simultaneously reduce the skin and inner resistances.

Table 5.1 Classifies the agricultural materials investigated in this study according to the above criteria. Once this classifcation is known, it will easy to know whether pretreatment is required, how to enhance drying rate, etc.

TABLE 5.1 CLASSIFICATION OF INVESTIGATED MATERIALS ACCORDING TO DRYING CHARACTERISTICS

Material	Type	Remark
Sapota(untreated)	Film-Resistance	
Grape(pretreated)	Film resistance	Grape(untreated) would be skin resistance
Jujube (pretreated)	Inner-Resistance	Jujube (untreated) would be skin and inner resistance

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5.2 Conclusions

Here are the main conclusions of this study.

1. Only the falling rate period was observed for all studied agricultural products.

2. The drying characteristics could be vary greatly from one material to another, even if they are of similar shape and size.

3. The drying characteristics depended on the properties of water contained within the material, whcich in turn depend on the characteristics of the inner material.

4. Increasing air temperature increased the drying rate of all materials. (The temperature should not be too high in case of drying agricultural products).

5. An air velocity of 0.6-1.2 m/sec had little effect on the drying rate of jujube, but considerable effect on the drying rate of sapota and grape (pretreatment).

6. Air humidity had appreciable effect on the drying of jujube but slight effect on sapota and grape (pretreated)

7. Mass transfer of inner resistance is rate controlling step for jujube(pretreated) and heat transfer of film resistance is rate controlling step for sapota and grape (pretreated)

8. The equilibrium moisture content of the dried products was influenced by the relative humidity and temperature of the hot air as well as the type of materials

5.3 Future Work

Any future work might consider the following:

1. Study the effect of drying conditions on the loss of aroma and nutritional value, etc.

2. Expand the scope of the experiments to cover more agricultural products.

3. Develop optimum operating conditions for fast, uniform and economical through-flow drying.

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