THESIS

This is to certify that the

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DRYING RATE OF INDIVIDUAL EARS OF CORN

By

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ABSTRACT

DRYING RATE OF
INDIVIDUAL EARS OF CORN

By

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The current drying process for seed corn relies primarily on the experience of the dryer operator. However, manual control of an ear-corn dryer can result in an inefficient process, with respect to dryer capacity and energy consumption.

Development of an automatic controller will allow dryer operators to operate seed-corn dryers more effectively and efficiently. However, development of a controller will require a drying model, and a thin-layer equation for ear-corn drying is an essential component of any ear-corn drying model.

Thin-layer ear-corn drying was performed experimentally, and a thin-layer drying rate model was parameterized for ear corn. The calibration data set consisted of 127 data sets (1,206 data points) and was made up of laboratory data (n_{sets} = 65, n_{points} = 901) and field data (n_{sets} = 62, n_{points} = 305). Tests were run with drying air temperatures between 35 and 45°C (95 and 115°F). Relative humidity ranged from 5 to 35%. The resulting thin-layer model was validated against an independent validation set (n_{sets} = 30, n_{points} = 152). Validation of the model against field data resulted in a standard error of prediction of 0.1147 for the moisture ratio and 3.8% (dry basis) for the moisture content. The ratio of standard error of calibration to standard error of prediction resulted in a value of 1.4, indicating good robustness of the model.

For Stephanie, my light, my life, my love.

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Lastly, a heart felt thank you to my Stephanie. Without you in my life, I fear I would be lost. Thank you for putting up with me and continuing to be there for me.

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NOMENCLATURE

<u>Friant and Sharaf (Section 2.4 and Chapters 4 and 5)</u>

M_o	Initial moisture content [decimal, dry basis]
M_e	Equilibrium moisture content [decimal, dry basis]
$\overline{M}$	Average moisture content [decimal, dry basis]
MRAT	Moisture ratio
k	Drying parameter [h^{-1}]
t	Time [h]
A, B, C D, n	Experimentally determined parameter values
T_{abs}	Absolute temperature [K]
r.h.	Relative Humidity [%]
α, β	Experimentally determined constants for drying

<u>Hamdy and Barre, 1969 (Section 2.5)</u>

M_g	Kernel average moisture concentration [%, dry basis]
M_e	Grain equilibrium moisture content [%, dry basis]
M_a	Moisture content in air [%, dry basis]
M	Moisture concentration inside the kernel [%, dry basis]
M_s	Moisture concentration in kernel surface [%, dry basis]
Θ_a	Air temperature [°F]
Θ_g	Kernel average temperature [°F]
S_a	Specific heat of dry air [0.24 Btu/lb °F]
S_v	Specific heat of water vapor [0.44 Btu/lb °F]

S_w Specific heat of water [1 Btu/lb °F]

S_g Specific heat of dry grain [Btu/lb °F]

y Kernel depth in drying bed [ft]

r Radial position inside the kernel [ft]

t Time [h]

ρ bulk density of grain [lb/ft^3]

α film coefficient (moisture) [ft/h]

β Constant of heat transfer to grain [h^{-1}]

L Latent heat of vaporization [Btu/lb]

D Moisture diffusion coefficient [ft^2/h]

R Kernel radius [ft]

G Airflow rate per unit area of dryer [lb/ft^2 h]

Baughman et al., 1970 (Section 2.5)

C Grain moisture ratio

D Dimensionless depth variable

G Mass flow rate of drying air [lb of dry air/h ft^2]

K Drying constant [h^{-1}]

L Latent heat of moisture evaporation [Btu/lb]

M Grain moisture [%, dry basis]

M_o Initial grain moisture [%, dry basis]

M_t Grain moisture at the dryer inlet [%, dry basis]

M_e Grain equilibrium moisture content [%, dry basis]

S_a Specific heat of air [Btu/lb °F]

T_e Equilibrium air temperature [°F]

T_o	Inlet drying air temperature [°F]
y	Kernel depth in drying bed [ft]
t	Time [h]
ρ	bulk density of grain [lb/ft^3]
Q	Grain flow rate [lb/h ft^2]

Ear-Kernel Moisture Relationships (Section 4.2)

MC_{Ear}	Ear corn moisture content [%, d.b.]
MC_{Kernel}	Kernel moisture content [%, d.b.]

Psychrometrics (Section 4.3)

h_{fg}	Latent heat of vaporization [J/kg]
P_{atm}	Atmospheric pressure [101,325 Pa]
P_v	Partial pressure of water vapor [Pa]
P_{vs}	Partial pressure of water vapor at saturation [Pa]
P_{vswb}	Partial pressure of water vapor at saturation with wet-bulb temperature [Pa]
P_{vsdb}	Partial pressure of water vapor at saturation with dry-bulb temperature [Pa]
T_{abs}	Absolute temperature [K]
T_{db}	Dry-bulb temperature [K]
T_{wb}	Wet-bulb temperature [K]
υ	Specific volume of moist air [m^3/kg]
W	Humidity ratio of moist air [kg H_2O/kg dry air]
Φ	Relative humidity [decimal]

CHAPTER 1

INTRODUCTION

Corn[1] is an important commodity grown in the United States of America, accounting for 254 million metric tonnes and approximately $26.5 billion in raw product value (USDA, 2000). Therefore, production, harvesting, drying, and storage of corn seed are a critical part of this market sector.

Corn is primarily harvested by two means: combining, which separates the seed from the cob (shelled corn) and picking as ear corn. To prevent mold growth and to preserve viability, corn must be dried to a moisture content of 10 to 15%, wet basis (w.b.) (11 to 18%, dry basis)[2]. This is accomplished primarily by using mechanical grain dryers.

There are two main methods of corn drying: fixed-bed drying and continuous-flow drying (Brooker et al., 1992). Brief descriptions of the major types are given in Table 1.1.

Corn is produced as grain, for food or feed and seed for planting in subsequent growing seasons. In the production of corn for seed, ear corn is picked at a moisture content of 30 to 40%. The seed is then dried to approximately 12% moisture content for safe storage. A main difference in the production of seed corn versus grain is the end-user definition of quality. For the livestock producer, nutrient value is important; in the cereal industry, minimum stress cracking is desirable; and, in seed production, the viability is paramount.

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[1] In this thesis, the word *corn* is used in the American sense, referring to *Zea Mays*.
[2] In this thesis, the moisture contents are expressed in wet basis, unless specified differently.

In the process of seed-corn production, drying the seed to a moisture content of 12 to 13% is essential to prevent spoilage during storage. The seed is dried while still on the ear. Ear-corn dryers are manually controlled and marginally efficient with respect to capacity and energy usage (i.e., capacity could be increased, and energy usage could be reduced). Figure 1.1 shows the schematic of a typical ear-corn drying system.

Table 1.1 Description of common grain dryer types.

Drying Type	Temperature	Description
In-bin	Low	Specific airflow is passed through the drying bed to reduce moisture content to desired level.
In-bin (Batch)	High	Large quantites of heated air are passed through a relatively shallow thickness of grain.
Crossflow	High	Grain flows from a wet-holding bin through the drying zone. Hot air is passed perpendicularly from the air plenum through the grain in the drying section. In the cooling section, cool air is similarly passed aver the grain.
Concurrent-flow	High	Grain flows from a wet-holding bin through the drying zone. Hot air passes through the drying zone in the same direction as the wet grain. In the cooling zone, cooling air flows opposite to the grain.
Counter-flow	High	Grain, drying air and cooling air flow in opposite directions through out the drying cycle.
Mixed-flow	High	Mixture of crossflow, concurrentflow and countercurrentflow grain drying. Grain flows over a series of staggered, alternate rows of intake and outlet air ducts. Air enters the grain froman open-bottomed intake duct and flows through the grain to the exhaust ducts.
Seed corn+	Low	Ear corn is dried in a fixed bed for use as seed. During the first part of the cycle, hot air passes upward through the bed. During the second stage of drying, air passes downward through the bed.

Source: Brooker at al. 1992
+ Copeland and McDonald 2001

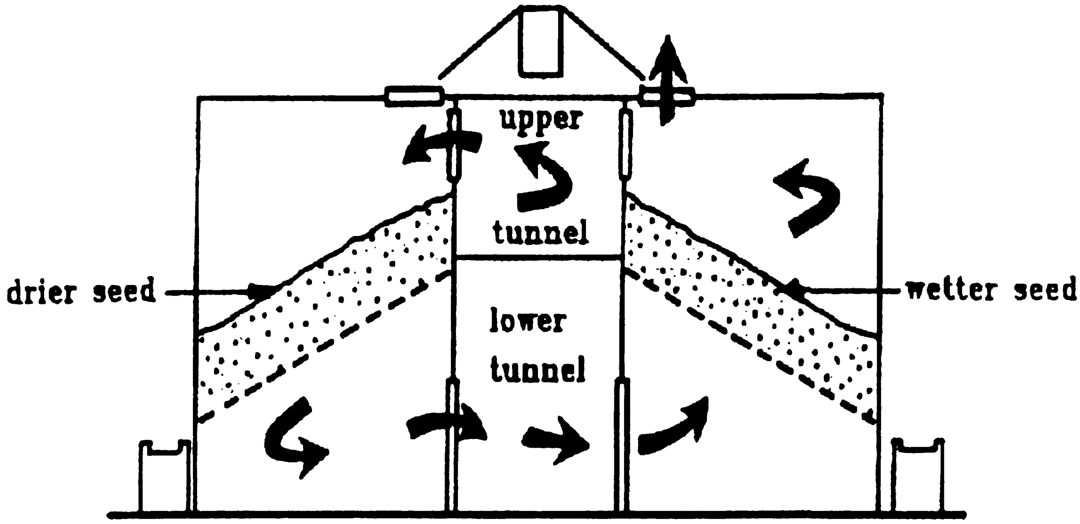

Figure 1.1 Schematic diagram of a fixed-bed ear-corn dryer (Cabrera, 2001).

A fixed-bed ear-corn drying unit consists of a two-plenum system with drying bins on each side of the plenum as seen in Figure 1.1. Several drying units are combined to form one ear-corn dryer, which uses one set of fans and burners for heating and circulating the drying air.

Ear corn is transported to the desired bin by a conveyor belt system. The corn is loaded into the appropriate bin through the top loading doors. The ear corn is piled on the slanted floor of the bin and filled to a depth of 2 to 3.5 m (7 to 11 feet). During the first stage of drying, the "up-air" drying air passes from the lower plenum through doors upwards through the drying bed, as indicated by the arrows, and is exhausted to the ambient through the loading doors. At the desired "reversal" time in the drying cycle, the airflow is reversed by closing the doors in the bin ceiling, and opening the doors of the upper plenum. The "down air" passes downward through the drying bed into the lower plenum, as indicated by the arrows. The air is recycled and used as the "up air" in other bins. When the correct final moisture content is reached (i.e., 12.5 ± 0.5%), the corn is unloaded through the unloading doors at the bottom of the drying bin.

To optimize the operation of an ear-corn dryer, a model of the drying process should be developed. Subsequently, formal control theory can be applied to find the optimum values of the main drying parameters (i.e., air temperature, bed depth, airflow, reversal time, shut-off time), which will result in the maximum production or minimum energy use of the dryer.

Historically, there has been little formal research aimed at ear-corn drying theory. Therefore, this thesis project was part of a larger research program with the overall goal of modeling, optimizing, and controlling fixed-bed ear-corn drying. However, before that overall goal can be achieved, it is first necessary to develop and validate various core elements that comprise a deep-bed drying model, including psychrometric routines, equilibrium moisture models, and thin-layer drying equations.

Therefore, in that context, the primary objectives of this research were: 1) to develop and validate a drying model for an individual ear of corn and 2) to contribute that model to a larger effort in developing a deep-bed model for the drying of ear corn.

CHAPTER 2

REVIEW OF LITERATURE

2.1 SEED TECHNOLOGY

Great strides have been made in the seed-production industry in the last 50 years. Copeland and McDonald (2001) listed six factors that have contributed to the growth of the seed industry:

1) An increased number of new varieties.
2) New seed-certification and seed-law enforcement programs.
3) Improved cleaning and conditioning technology.
4) Better understanding of seed quality.
5) Specialization of seed growers.
6) Greater seed industry sophistication.

The Hatch Act of 1875 laid the groundwork for the seed industry by establishing a network of experimental stations throughout the United States. A direct effect of the Hatch Act was the development of the seed certification program.

2.2 CORN HYBRIDIZATION

2.2.1 TRADITIONAL CORN HYBRIDIZATION

The hybridization of corn was a major step in the production of seed. In 1908, the advantages of hybrid corn compared to open-pollinated corn were first published. Double-cross seed was produced in 1917; its acceptance grew rapidly, leading to nearly 100% use today (Copeland and McDonald, 2001).

There are good reasons for using hybrid seed instead of inbred lines. As corn is inbred, the general characteristics soon become apparent, resulting in smaller, less vigorous, later maturing, lower yielding plants. There is also an increase in uniformity with subsequent generations. Conversely, the first progeny of hybrid seed is more vigorous, taller, higher yielding and earlier maturing than those of inbred seed. Hybrid seed is produced by cross-pollinating two inbreds or a series of inbreds and hybrids (U of W, 2001).

Currently, there are four main types of cross-pollination hybrids on the market: a) single-cross, b) modified single cross, c) double-cross, and d) three-way cross (Copeland and McDonald, 2001) (Figure 2.1).

Single Cross	
A x B → AB	

Modified Single Cross		
A x A' → AA'		AA' x BB' → AA'BB'
B x B' → BB'		Or
B = Pure inbred		AA' x B → AA'B

Double Cross	
A x B → AB	AB x CD → ABCD
C x D → CD	

Three-way Cross	
A x B → AB	AB x C → ABC

Figure 2.1 Types of hybrid crosses (U of W, 2001)

In each of the commercially available crosses illustrated in Figure 2.1, the inbred lines have been in development for at least five successive generations. Thus, hybrids go through a rigorous selection process to ensure quality seed for different growing conditions. Therefore, hybrid seed has to be produced under a variety of conditions (e.g., low fertility, no-till, or irrigation). Seed is also evaluated for disease and insect resistance (U of W, 2001).

For many years, double-cross pollination was the standard hybrid corn (See Figure 2.1). These hybrids have many desirable characteristics (Copeland and McDonald, 2001), such as:

1) greater genetic variability than single or three-way crosses, which may help the plant during unfavorable growing conditions,
2) longer pollination period for improved seed fill on the ear, which leads to higher yield,
3) lower cost when the yield is equal to or better than single and three-way crosses, and
4) higher seed quality than single-cross hybrids.

In recent years, the use of single-cross hybrids has become more common. In these hybrids, two parent plants are cross-pollinated to yield one offspring (See Figure 2.1). The seed produced from this cross has the following desirable traits: a) a good plant uniformity in plant height, ear height, tasseling time, silking, and pollen shed; b) higher disease and insect resistance; and c) higher genetic yield potential than the best double cross. Disadvantages of the single-cross hybrid are a lower seed yield and a relatively low seed quality, because seed is produced on inbred parents (Copeland and McDonald, 2001).

In modified single-cross corn (Figure 2.1), two related sister-inbred lines (A and A') are crossed to produce the female (seed) parent. Also, two other related sister-inbred lines (B and B') can be cross-pollinated resulting in the male (pollen) parent. The female parent is then cross-pollinated with the male parent or a straight inbred (B). Figure 2.1 shows the crosses and progeny in modified single-cross hybridization. These hybrids are more vigorous and produce higher-quality seed than full inbreds.

In three-way cross-pollination, a single-cross parent is crossed with an unrelated parent inbred (Figure 2.1). In general, three-way crosses tend to fall in between single- and double-crosses with respect to cost, yield and variability (Biotech-Monitor, 2001). Three-way crosses are usually less uniform than single-cross hybrids and normally have higher yields than double cross hybrids (Heiniger, 2001).

2.2.2 GENETIC MODIFICATION (PLANT BIOTECHNOLOGY)

Modern hybrid development is aided by genetic modification. Plant biotechnology allows for the transfer of a variety of genetic information in a precise, controlled manner (Monsanto, 2000). Figure 2.2 shows the comparison between traditional plant breeding and modern plant biotechnology (Adapted from the Council for Biotechnology Information, 2000).

In plant biotechnology, enzyme "scissors" are used to cut a desired gene segment from a chain of DNA (deoxyribonucleic acid) followed by cutting an opening in the plasmid[1] of the DNA chain into which the desired gene segment is inserted. The desired gene is placed in the plasmid. The chemical make-up of the cut ends of the gene segment and the plasmid bond to form a new plasmid

[1] The plasmid is the rind of DNA found in the bacteria outside of a cell.

(Monsanto, 2000). Many new corn hybrids have been a direct result of the enzyme scissors technology

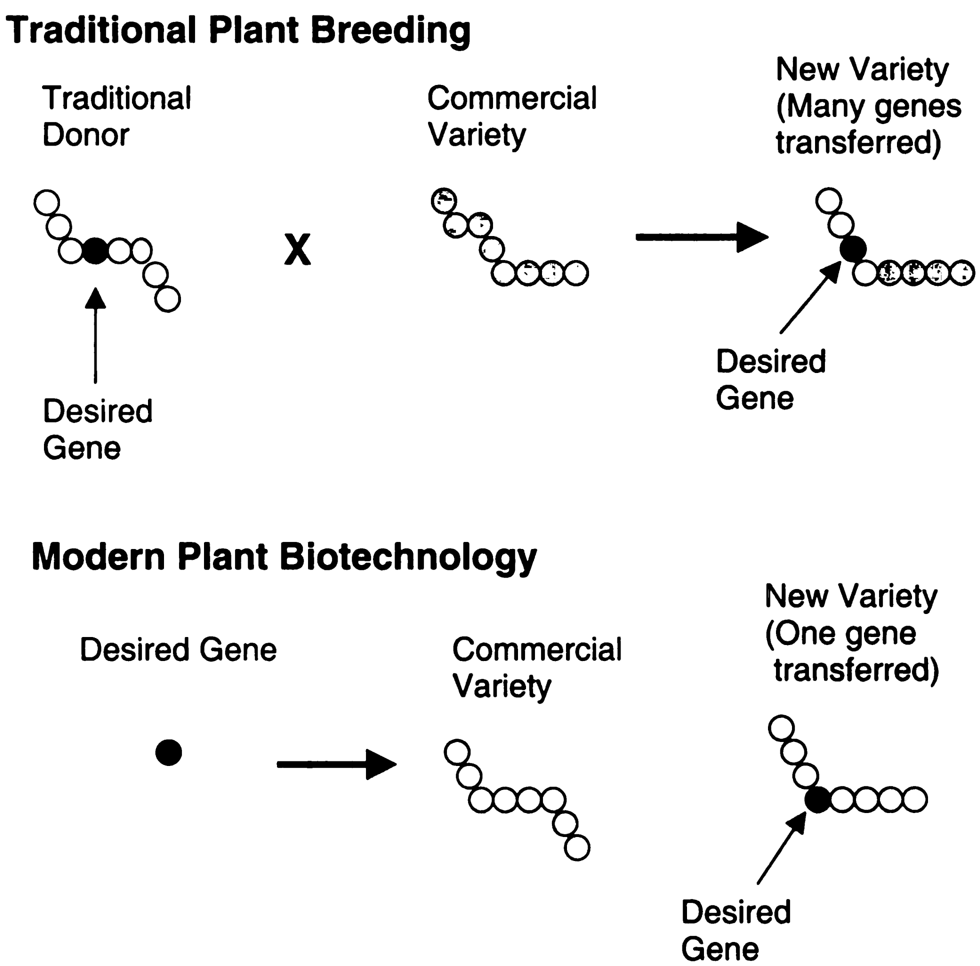

Figure 2.2 Comparison of traditional plant breeding and modern plant biotechnology. (Adapted from the Council for Biotechnology Information, 2000)

2.3 SEED PRODUCTION PRACTICES

Seed-production practices vary widely, depending upon location, climate, seed cost, hybrid-development rate, seed type, and grower planting practice (Hunter, 2002). This section explains the common choices of cross-type and row-pattern selections.

As shown previously, single-cross hybrids have become common in recent years. These hybrids are generally grown in temperate, low-stress environments. Three-way hybrids are commonly produced where challenging growing conditions are present (e.g., the tropics). Decisions for producing a double-cross hybrid depend on: the seed price, and low production of new hybrids. The value of higher yielding seed lines is offset by the higher potential seed yields of double-crosses (Hunter, 2002).

The row pattern in seed production varies greatly. The basic row patterns are 4:1(i.e., four rows of female (seed) parent to one row of male (pollen) parent), 4:2, 6:1, and 6:2. Regardless of the planting pattern, the female rows are detasseled, allowing the male rows to pollinate the female rows. Female plants may also be male-sterile (i.e., the male portion of the plant, the tassel, is sterile and thus the plant does not pollinate itself). It should be noted that these plants have a self-restoring mechanism, and thus the next generation of seed produces both pollen and seed again (Copeland and McDonald, 2001).

Four general attributes govern the row-pattern selection in seed production: the number of row units on the grower's planter, the use of a split-planted male (i.e., the male seed is planted after the female seed), the strength (vigor) of the male, and the row width. Generally, an attempt is made to balance the multiple considerations, so that the best combination of management practices is selected (Hunter, 2002).

Once seed corn is produced, it is important to understand and model the subsequent drying process.

2.4 THIN-LAYER DRYING

It is assumed that in the thin-layer drying of corn, liquid water in the corn kernel and/or cob diffuses to the surface where it is evaporated. This follows Fick's law of diffusion, which states that mass flux per unit area is proportional to the concentration gradient (Holman, 1997). This process is known as falling-rate drying, where the drying rate is dependant on the rate of moisture transfer from the interior to the surface of the grain (Laws and Parry, 1983).

Thin-layer drying is a process during which drying air is passed though a thin layer of corn for a given interval (Thompson et al., 1968). During the time interval, moisture is evaporated from the corn into the air. The point of thin-layer drying is to keep the grain in contact with constant air conditions (e.g., air temperature and relative humidity).

Fickian diffusion principles have been applied to the drying of corn by numerous researchers (Laws and Perry, 1983; Thompson et al., 1968; Henderson and Henderson, 1968; Chu and Hustrulid, 1968; Tolaba et al., 1997; Mourad et al., 1996; and Parti and Dugmanics, 1990). However, the application of Fick's Law to drying ear corn considers questionable assumptions: ears of corn and kernels are a regular shape (i.e., spheres) and the kernels are homogeneous. When applied to single kernels of corn, this process can be theoretically modeled. Practically, the use of Fickian diffusion is time consuming and difficult, because of the non-homogeneity of corn, especially ear corn, which necessitates numerical solutions.

Because of the difficulty applying Fickian diffusion to corn drying, researchers have tended to work more with empirically derived models. Examples of empirical models are those developed by Lewis (1921), Page (1949), and Sharaf-Eldeen et al. (1980). The Lewis model is a simple exponential model:

$$MRAT = e^{-kt} \tag{2.1}$$

The Page model incorporates a second variable, n:

$$MRAT = \exp(-kt^{n}) \tag{2.2}$$

The Sharaf-Eldeen model is a two-term model using two constants, A and B, as well as the drying parameter k. The Sharaf model will be discussed later in this section.

Thompson et al. (1968) performed thin-layer tests with shelled corn to investigate the effects of drying air temperature. The experimental thin-layer dryer for these tests simply consisted of a fan blowing heated air upward through a screened tray holding the corn samples. The tests of Thompson et al. showed that air temperature was the main factor affecting the drying rate.

Li and Morey (1984) performed thin-layer tests to fit Page's equation to shelled corn drying data. The thin-layer drying apparatus used by Li and Morey delivered air with set temperature and relative humidity to a sample that was being dried on an automatic weighing rack constructed of sheet metal and wire mesh. To correct for the buoyancy effect of the airflow over the sample, weights with air flowing and no air flowing were recorded and used to correct the recorded weights. The weight was recorded every 10 seconds.

The experiments of Li and Morey (1984) produced five important conclusions:

1) drying air temperature has the most significant effect on the drying rate of corn in thin-layers,
2) airflow rates over 0.1 to 0.5 m/s have little effect on the drying rate,
3) initial moisture content significantly affects the moisture ratio,
4) relative humidity has a minor affect on the moisture ratio and can be neglected, and
5) Page's model provides a suitable description of thin-layer drying rates for corn at 27 to 116°C and 23 to 26% (d.b.).

Sharaf-Eldeen et al. (1980) performed thin-layer drying experiments to develop a two-term thin-layer drying model for ear corn. A laboratory dryer was equipped with temperature, relative humidity, and air velocity controls. The weight of the drying samples was recorded using an automatic weight system comprised of cantilever beams with strain gages attached. The cantilever beams were calibrated using weights up to 500 g to compensate for the buoyancy effects of the airflow. Air temperatures and relative humidities for the test were 35.2, 54, 74°C and 13.4, 16.0, and 5.0%, respectively.

From experimental data, Sharaf-Eldeen et al. (1980) developed the following thin-layer equation for the drying of ear corn:

$$\frac{\overline{M} - M_e}{M_o - M_e} = Ae^{-kt} + (1 - A)e^{-Bkt} \tag{2.3}$$

The constants A and B were chosen to fit the experimental data. The assumption was made that the drying curves of fully exposed ear corn can be simulated by two straight lines on a semi-log plot. Equilibrium moisture content was calculated from:

$$M_e = \left[\frac{-\ln(1 - r.h.)}{T_{abs}} \right]^{0.55} \tag{2.4}$$

The drying parameter (k) was determined from:

$$k = \exp\left[6.8 + (0.0195T_{abs} - 9.75)M_0 - \frac{2619}{T_{abs}} \right] \tag{2.5}$$

Equations (2.3), (2.4), and (2.5) comprise the two-term, Sharaf thin-layer drying model.

2.5 THE OSU MODEL

A deep-bed simulation model of grain drying was developed in the 1960s and 1970s by Barre and associates at The Ohio State University (Hamdy and Barre, 1969; Baughman et al., 1970; and Barre et al., 1971). The logarithmic model combines an empirical approach with some fundamentals of heat and mass transfer.

The drying process is modeled by a series of five partial differential equations:

1) air temperature,
2) absolute humidity,
3) grain temperature,
4) local grain moisture content, and
5) average grain moisture content.

The five simultaneous equations have five unknowns, which results in a unique solution for a given set of boundary conditions. The boundary conditions are Equations (2.11) to (2.14).

Equation List 2.1 Deep-bed drying equations and boundary conditions (Hamdy and Barre, 1969)

$$\left(S_a + m_a S_v\right)\frac{\partial \Theta_a}{\partial y} = \frac{\rho}{G}\left(\Theta_g - \Theta_a\right)\left[\beta S_g - S_v \frac{\partial m_g}{\partial t}\right] \tag{2.6}$$

$$\frac{\partial m_a}{\partial y} = \frac{\rho}{G} - \frac{\partial m_g}{\partial t} \tag{2.7}$$

$$\left(S_g + m_g S_w\right)\frac{\partial \Theta_g}{\partial t} = -\beta S_g\left(\Theta_g - \Theta_a\right) + L\frac{\partial m_g}{\partial t} \tag{2.8}$$

$$\frac{\partial m}{\partial t} = \frac{D}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial m}{\partial r}\right) \tag{2.9}$$

$$m_g = \frac{3}{R^3}\int_0^R m r^2 dr \tag{2.10}$$

$$\Theta_a(t,0) = \Theta_1 \tag{2.11}$$

$$m_a(t,0) = M_1 \quad (2.12)$$

$$\Theta_g(0,y) = \Theta_0 \quad (2.13)$$

$$m(0,y,r) = M_0 \quad (2.14)$$

$$\left.\frac{\partial m}{\partial r}\right|_{r=0} = 0 \quad (2.15)$$

$$\left.D\frac{\partial m}{\partial r}\right|_{r=R} = -\alpha(m_s - m_e) \quad (2.16)$$

The equilibrium moisture content (EMC) in Equation (2.17) is a function of the air temperature and moisture content

$$m_e = m_e(\Theta_a, m_a) \quad (2.17)$$

The equations in Equation List 2.1 became the basis for a computer simulation model (Hamdy and Barre 1969). The solution to the model gives transient temperature and moisture profiles for the drying air and grain. Due to the complicated nature of solving the system of equations, Hamdy and Barre developed a computer program. This program assumed that the deep-bed drying can be modeled as a series of thin layers. An important assumption in the model is that the temperature and moisture content of each layer is uniform, but changes with respect to time and from layer to layer.

Because of the two independent variables, t and r, in the equations for moisture transfer in the grain layer (Equations [2.8] to [2.10]); r was eliminated as a variable. This was done by treating individual kernels as 10 concentric spherical shells. This process yields 10 simultaneous ordinary differential equations. The equations for the air temperature and moisture were solved by finite differences. Equation List 2.2 shows the modified equations for the deep-bed drying simulation.

Equation List 2.2 Modified deep-bed equations and boundary conditions (Hamdy and Barre, 1969).

$$\frac{d\Theta_g}{dt} = \left[\beta S_g\left(\Theta_a - \Theta_g\right) + L\frac{dm_g}{dt}\right] \div \left(S_g + m_g S_w\right) \tag{2.18}$$

$$\frac{dm_i}{dt} = 100\frac{D}{R}\sum_{j=i-1}^{i+1} a_{ij} m_j ; for \rightarrow i = 0,1,\ldots,9 \tag{2.19}$$

$$m_g = \sum_{i=1}^{9} b_i m_i \tag{2.20}$$

$$\frac{dm_g}{dt} = 100\frac{D}{R^2}\sum_{i=0}^{10} C_i m_i \tag{2.21}$$

$$m_S = \left(\frac{30D}{\alpha R} m_9 - \frac{10D}{3\alpha R} m_8 + m_e\right) \div \left(1 + \frac{80D}{3\alpha R}\right) \tag{2.22}$$

$$L = L\left(m_g\right) \tag{2.23}$$

$$\frac{D}{R^2} = \frac{1}{R^2} D\left(m_g\right) \tag{2.24}$$

$$C_i = \sum_{j=i-1}^{i+1} b_j a_{ji}; for \rightarrow i = 0,1,\ldots,9 \tag{2.25}$$

$$\Delta\Theta_a = \Delta y \frac{\rho}{G}\left[S_g - S_v \frac{dm_g}{dt}\right](\Theta_g - \Theta_a)/(S_a + m_a S_v) \tag{2.26}$$

$$\Delta m_a = -\Delta y \frac{\rho}{G}\frac{dm_g}{dt} \tag{2.27}$$

The boundary conditions are:

$$\Theta_a(t,0) = \Theta_1 \tag{2.28}$$

$$m_a(t,0) = M_1 \tag{2.29}$$

$$\Theta_g(0,y) = \Theta_0 \tag{2.30}$$

$$m_i(0,y) = M_0; i = 0,1,\ldots,9 \tag{2.31}$$

Baughman et al. (1970) expanded on the work of Hamdy and Barre (1969). A diffusion model replaced the thin-layer equation in the logarithmic model. The following assumptions were made:

1) Change in sensible heat of the air due to moisture gain is negligible.
2) Sensible heat required to raise the grain temperature is negligible compared to the latent heat of moisture vaporization.
3) Sensible heat used to raise the temperature of removed water vapor to air temperature is very small.

4) The grain bulk density (ρ) and the latent heat of vaporization (L) are assumed not to change with grain moisture or temperature.

Using these assumptions, the heat transfer equation of Hamdy and Barre (1969) (Equation [2.26]) was reduced to:

$$S_a G \frac{\partial T}{\partial y} = \rho L \frac{\partial M}{\partial t} \qquad (2.32)$$

Next, Baughman et al. (1970) introduced the concept of the travel rate (Q) of the drying front with respect to the airflow rate. Then, from Equation (2.32):

$$G S_a \frac{\partial T}{\partial y} = -Q L \frac{\partial M}{\partial y} \qquad (2.33)$$

where:

$$Q = \frac{T_o - T_e}{M_o - M_t} \frac{S_a G}{L} \qquad (2.34)$$

Substitution of Equations (2.32) and (2.33) into Equation (2.34) and simplification by use of dimensionless variables leads to:

$$\frac{\partial C}{\partial \Theta} = \frac{-1}{1 - C(0,\Theta)} \frac{\partial C}{\partial D} \qquad (2.35)$$

where:

Moisture ratio → $C = \frac{M_o - M_e}{T_o - T_e}$

Time variable → $\Theta = kt$

Depth variable → $D = \dfrac{L(M_o - M_e)ky\rho}{GS_a(T_o - T_e)}$

The results of Baughman et al. (1970) show that the diffusion model is more accurate than the logarithmic model (i.e., the measured and computed moisture ratios show closer agreement).

The general drying model developed by Hamdy and Barre (1969), Baughman et al. (1970), and Barre et al. (1971) was subsequently adapted for ear-corn drying. Internal reports of this research have been made available to the author, but due to the confidentiality of these reports, they cannot be incorporated into this thesis. Islam (2002,b) showed that the standard error for predicting dryer shut-off time with the OSU model is greater than 20 h.

2.6 COB-KERNEL MOISTURE CONTENT RELATIONSHIP

During drying, the drying of the corn cob lags behind the drying of the kernels, which affects the normal cob-kernel moisture relationship. However, the effect is not unduly severe. The cob and kernel moisture content, if given the chance, will equilibrate (Schmidt, 1948). A conversion chart to determine the cob-kernel moisture relationship can be found in Schmidt (1948). In this study, moisture content for the entire ear (i.e., cob and kernels) is used for the laboratory data. Field data were recorded as kernel moisture content and converted to ear moisture content using an equation regressed from the data presented in Schmidt (1948). The conversion equation from kernel to ear moisture content is discussed in Chapter 4.

CHAPTER 3

EXPERIMENTAL PROCEDURES

3.1 OVERVIEW

In the development and validation of the computer simulation model for ear-corn drying, two primary types of experimental data were collected: field data and laboratory data. Field data were collected in Constantine, Michigan at the Pioneer Hi-bred International, Inc. seed production plant. The data were used in the development and validation of the thin-layer, ear-corn drying equation and deep-bed, ear-corn drying model. Ear corn samples taken from the research site (at 25 to 38% [w.b.] moisture content) were also used in laboratory thin-layer drying.

The complete data set (n_{sets} =157, n_{points} =1,358) was separated into a calibration set (n_{sets} =127, n_{points} =1,206) and a validation set (n_{sets} =30, n_{points} =152). The calibration set consisted of laboratory data (n_{sets} =65, n_{points} =901) and field data (n_{sets} =62, n_{points} =305). The 30 data sets used in the validation set were removed from the set of field data using a random number generator and were used to determine the standard error of prediction of the parameterized thin-layer model.

3.2 FIELD EXPERIMENTATION

3.2.1 DATA COLLECTION

Data collected in Constantine, Michigan consisted of transient data for the deep-bed drying cycle. Three drying bins were designated as research bins for the MSU research team. During the drying season, which began on September 1, 2002 and ended October 30, 2002, the researchers were given control of the three designated bins. For each drying cycle, initial and final moisture content data, as well as transient moisture content data were collected.

To monitor drying, moisture content samples were taken at the bottom and top of the drying bed prior to unloading. If the samples were within the recommended moisture content range for shelling (12.5% ±0.5%), the bin was unloaded. If sample moisture contents were not within the acceptable range, the dryer was restarted.

3.2.2 MOISTURE CONTENT SAMPLE COLLECTION

Moisture content data consisted of three sets: 1) initial moisture content, 2) transient moisture content, and 3) final moisture content. Initial moisture content was determined by Pioneer employees during bin loading. Samples for transient moisture content analysis were collected by MSU researchers at eight-hour intervals during the drying cycle. Final moisture content was taken from the moisture content metered by Pioneer employees during corn shelling.

During bin loading, random samples were shelled by Pioneer employees, and the moisture content of these samples was measured using a Dickey-John GAC 2000 moisture meter (Dickey-John Corp., Auburn, IL). Specifications and operation parameters for the GAC 2000 are in Appendix C.

Two methods were employed to collect moisture content samples during the drying cycle. Samples from the bottom of the drying bed were removed directly from the unloading doors at eight-hour intervals. Samples to be collected from the top of the drying bed were placed in plastic mesh bags during bin loading. Mesh bags were selected for use, because they minimally disturbed the airflow around the ear corn. After loading was complete, ropes were tied to the sample bags. The bags were then placed on top of the drying bed in a linear pattern at three sampling points. The bags were removed approximately every eight hours, during the drying cycle, and ears were taken from each bag to check moisture content. Moisture content samples were shelled from the cob and moisture content was measured with the Dickey-John GAC 2000.

Final moisture content for each drying cycle was taken from the moisture content determined during shelling. During shelling, moisture content was continuously monitored using a GAC 2000 moisture meter. The final moisture content that was recorded was the average moisture content measured for the entire bin. In situations where the initial data showed that corn was under-dried, shelling was stopped, and airflow was returned to the unshelled corn remaining in the bin.

3.3 LABORATORY EXPERIMENTATION

3.3.1 DATA COLLECTION

Experimentation and data analysis were carried out in the laboratory using samples taken from the research bins in Constantine, Michigan at the start of drying (27 to 36% moisture content, wet basis). Thin-layer tests were performed to develop and validate the thin-layer drying equation to be used in the deep-bed simulation of ear-corn drying.

3.3.2 THIN-LAYER TESTS

Thin-layer drying tests were performed in a DX-400 gravity-convection oven (Yamato Scientific America Inc., Oragenburg, NY). Specifications for the oven are in Appendix C. Thin-layer tests were conducted at three drying temperatures: 35, 40, and 45°C (95, 104, and 113°F, respectively).

Before drying, the oven was set to the desired temperature and allowed to reach steady state. To achieve airflow of 0.3 m/s specified in ASAE Standards (2000, a), a fan was placed in the oven. The airflow was measured using an air velocity probe for the Solomat MPM 500e (Lumidor Safety Products, Miramar, FL). Each sample was wrapped in a plastic mesh cloth. Similar to the field tests, this insured that no kernels broke off the ear corn during drying. Each sample was weighed and placed in the oven. Samples were arranged in a pattern such that no samples were placed directly over the fan. Figure 3.1 shows the pattern of the ears on the drying rack and the mesh covering used to contain the shelled kernels.

During drying, the weight of each sample was recorded hourly for the first eight hours of drying. After that, samples were weighed periodically until weight loss became negligible. At the end of the thin-layer drying test, an oven test (103°C, 72 h) was performed to determine the final moisture content of the ear corn (ASAE, 2000, b) (Figure 3.2). The moisture contents for the thin-layer drying cycle were then back calculated from this value and the associated weight changes during drying. The moisture contents and moisture ratios from the thin-layer tests were used to develop the thin-layer drying equation.

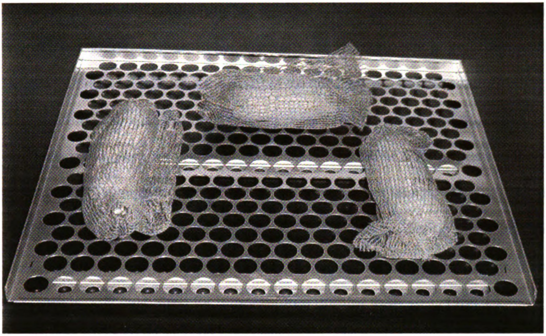

Figure 3.1 Ear corn samples in plastic mesh on oven drying rack.

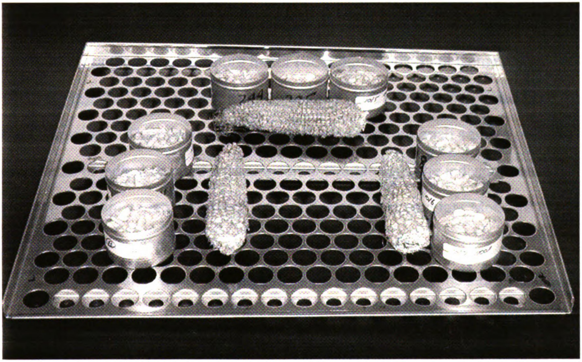

Figure 3.2 Shelled corn and cobs on drying rack for 72 h drying.

The temperature and relative humidity were monitored in the laboratory with a Bionaire digital thermo/hygrometer (The Holmes Group, Inc., Milford Massachusetts). Each time the sample weights were taken, the laboratory temperature and relative humidity were recorded. During two tests, the relative humidity in the oven was recorded with a Solomat MPM 500e for use in the validation of the equilibrium moisture content equation used by Sharaf-Eldeen et al. (1980). This will be discussed further in Chapters 5. During the 35°C (95°F) tests, temperature was recorded in the oven with a Solomat MPM 500e, because the oven is only calibrated for temperatures greater than 40°C (104°F).

3.3.3 CALIBRATION TESTS

Ear corn samples were taken at the Constantine research location and dried in the laboratory to determine a calibration constant for the GAC 2000 and the PQ-100 single kernel moisture meter (Seedburo Equipment Company, Chicago, IL). Two ears of corn for each sample were shelled and placed back in the sample bag. The shelling and mixing of two ears from each sample reduced the effects of individual seed moisture content variability. The individual seed moisture content variability will be discussed later in this chapter. Moisture content was determined via an oven test (ASAE, 2000, b).

Table 3.1 shows the calibration data for the GAC 2000 moisture meter and the calibration bias of -0.2% (i.e., the actual moisture content is the moisture content measured by the GAC 2000 minus 0.2%). Table 3.2 shows the calibration data for the PQ-100 and the calibration bias of + 1.8% (i.e., the actual moisture content is the moisture content measured by the PQ-100 plus 1.8%).

Specifications for the PQ-100 are in Appendix C.

Table 3.1 Calibration data for the GAC 2000 moisture meter.

Sample	Oven Moisture Content (%, w.b.)	GAC 2000 Moisture Content (%, w.b.)	Difference (%, w.b.)
1	16.1	17.1	-1.0
2	17.0	15.2	1.8
3	17.8	20.1	-2.3
4	17.9	17.6	0.3
5	18.4	21.7	-3.3
6	20.5	20.6	-0.1
7	21.0	25.4	-4.4
8	21.3	21.0	0.3
9	23.4	22.0	1.4
10	24.2	22.8	1.4
11	24.7	23.6	1.1
12	27.6	25.2	2.4
		Average Difference	-0.2

Table 3.2 Calibration data for the PQ-100 single-kernel moisture meter.

Sample	Oven Moisture Content (%, w.b.)	PQ-100 Moisture Content (%, w.b.)	Difference (%, w.b.)
1	15.3	14.7	0.6
2	16.4	14.5	1.9
3	17.3	15.9	1.4
4	17.4	15.6	1.8
5	18.2	16.7	1.5
6	18.4	16.5	1.9
7	18.5	16.5	2.0
8	18.8	16.5	2.3
9	19.2	17.3	1.9
10	20.9	18.1	2.8
		Average Difference	1.8

3.3.4 SINGLE KERNEL MOISTURE TESTS

Two separate sets of single kernel moisture content data were used to show the variability of moisture content of individual kernels on the same ear of corn. In both tests, the PQ-100 single-kernel moisture meter was used. To demonstrate the moisture content variability, the single-kernel moisture content was measured for each kernel on an ear of corn. Corn kernels were shelled from a sample one row at a time, keeping the kernels in the same order they came off the cob. The moisture content of each individual kernel was measured and recorded. Variability of the individual kernel moisture content will be further discussed in Chapter 5.

3.3.5 DATA ANALYSIS

Data from the thin-layer tests were arranged in a spreadsheet in the following order: sample code number, drying time, moisture ratio, initial moisture content, and drying-air temperature. For the nonlinear regression, the nominal temperatures were used for the laboratory data and the average temperatures for each drying run were used for the field data. For the laboratory data, the average temperature for each experiment differed from the nominal value by less than ±1.5°C. For the field data, the average temperature for each data set differed from the temperature calculated by Pioneer by less than ±1.5°C. The complete data set, less the 30 validation sets, can be found in Appendix A.

An iterative process was used to calculate the least-squares estimates of model parameters for the specified equation form (equation forms are discussed in Chapter 4). The iterative process consists of the Gauss-Newton method with stephalving (SAS Institute, 2001). The analytical derivatives of the prediction formula, with respect to the parameters, are taken to calculate the least-squares estimates of the parameters. If the analytical derivative cannot be calculated, the numerical derivative must be calculated. The Newton-Raphson method is used when the parameter values do not have a linear relationship; the Newton-Raphson method utilizes the second derivatives of the prediction formula (SAS Institute, 2001).

The nonlinear regression procedures were implemented via JMP statistical software (SAS Institute, 2001). The Nonlinear Fit Platform (nonlinear regression user interface in JMP) automatically calculates the derivatives of the prediction formula with respect to the parameter values. When using the second derivative option, JMP automatically calculates the second derivatives of the prediction formula and uses the Newton-Raphson method (SAS Institute, 2001).

The data were imported into the JMP program along with the thin-layer model. Initial guesses for the parameters were made before the JMP nonlinear regression was run. The JMP software was run until the parameter values converged. The converged parameter estimates formed the basis for the new, thin-layer model described in Chapter 4. Table 3.3 shows the form of the spreadsheet used in the JMP software. Columns one through five contain the code number and input data used for the nonlinear regression. Column 6 shows the output of the thin-layer model when using the parameter values.

Table 3.3 Example of JMP spreadsheet

Code	Drying Time	Moisture Ratio	Initial M.C. (%)	Temp. C	Thin-layer Model MRAT
1	0	1.0000	45.6	40.0	1.0000
1	1	0.9855	45.6	40.0	0.9677
1	2	0.9662	45.6	40.0	0.9374
1	3	0.9444	45.6	40.0	0.9083
1	4	0.9154	45.6	40.0	0.8804
1	5	0.8961	45.6	40.0	0.8534
1	7	0.8550	45.6	40.0	0.8023
1	8	0.8405	45.6	40.0	0.7781
1	22	0.6206	45.6	40.0	0.5092
1	25	0.5796	45.6	40.0	0.4655
1	45	0.3403	45.6	40.0	0.2570
1	53	0.2461	45.6	40.0	0.2030
1	72	0.1470	45.6	40.0	0.1163
1	94	0.0673	45.6	40.0	0.0613

Figure 3.3 shows the typical output produced by the JMP software. When the nonlinear fit is used, the text appearing below the word "Report" tells the user the status of a run. In the case of Figure 3.3, the data yielded converged parameters. The iteration row shows the number of iterations and the stop limit for the number of iterations. In the case of Figure 3.3, the total number of iterations was 17, and the stop limit was 60. If 60 iterations are performed, and the parameter values do not converge, the program stops running. The "Current Value" column displays the values of the parameters while the software is running.

Nonlinear Fit

Control Panel

Report

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	17	60
Shortening	0	15
Obj Change	5.411593e-9	0.0000001
Prm Change	0.0086252117	0.0000001
Gradient	1.91451155e-8	0.000001

Parameter	Current Value	Lock
A	-5.88861043	☐
B	0.2450542763	☐
C	0.148025225	☐
D	9.062231416	☐
n	0.9702265594	☐

SSE 3.4387606943

N 871

Edit Alpha	0.050
Convergence Criterion	0.05
Goal SSE for CL	.

Solution

SSE	DFE	MSE	RMSE
3.4387606943	866	0.0039709	0.0630147

Parameter	Estimate	ApproxStdErr	Lower CL	Upper CL
A	-5.88861043	20.3593403	.	.
B	0.2450542763	0.84725309	.	.
C	0.148025225	149431.012	.	.
D	9.062231416	4382720.98	.	.
n	0.9702265594	0.01112992	.	.

Figure 3.3 Typical output for JMP nonlinear regression.

The Sum of Squares Error and the number of data points used are displayed to the right of the parameter values. Root Mean Square Error (RMSE) is shown in the solution.

Sum of squares error (SSE) is the sum of the residual values (the difference between actual values and predicted values) squared. As this number gets smaller, the predictive model is more closely predicting the experimental values. The mean squared error (MSE) is the SSE divided by the number of total data points (n) minus 1 (n-1). As with the SSE, as the MSE decreases, there is a closer fit between the predicted data and experimental data. RMSE, the root mean square error, (standard error of calibration [SEC]) describes the error of the predicted data versus the experimental data used to develop the parameter values. When the RMSE decreases, the prediction model is more accurately modeling the experimental data.

CHAPTER 4

EQUATION DEVELOPMENT

4.1 THIN-LAYER EQUATIONS

In this research, two main forms of the thin-layer drying equation were investigated: one form recommended in the ASAE Standards (2000, a), and one form developed by Sharaf-Eldeen et al. (1980). The form in the ASAE Standards is a one-term model containing the drying constant (k), the time in the drying cycle (t), and an exponent (n). The Sharaf-Eldeen equation contains two coefficients (A, B), as well as the drying constant (k) and time (t).

4.1.1 ASAE STANDARDS THIN-LAYER MODEL

The general form of the thin-layer equation in ASAE Standards (2000, a) is the one-term Page (1949) model:

$$MRAT = \frac{\overline{M} - M_e}{M_o - M_e} = \exp\left(-kt^n\right) \tag{4.1}$$

An equation for the drying constant (k) was derived by Chu and Hustrulid (1968); it has the following form:

$$k = \alpha \exp\left(\beta M_0\right) \tag{4.2}$$

For ear corn, the following expressions were used for constants α and β:

$$\alpha = A \exp\left(-\frac{B}{T_{abs}}\right) \tag{4.3}$$

and

$$\beta = CT_{abs} - D \tag{4.4}$$

By substituting Equations (4.3) and (4.4) into Equation (4.2), the equation for the drying parameter (k) becomes:

$$k = \exp\left(A + \left(CT_{abs} + D \right) M_o + \frac{B}{T_{abs}} \right) \tag{4.5}$$

The resulting equation for the moisture ratio is:

$$MRAT = \exp\left(-\exp\left(A + \left(CT_{abs} + D \right) M_o + \frac{B}{T_{abs}} \right) * t^n \right) \tag{4.6}$$

The parameters of Equation (4.6) were estimated via nonlinear regression of the model against the calibration set of the experimental drying data.

Be rearranging Equation (4.1) the average moisture content of the ear corn at any time during the drying cycle can be calculated:

$$\overline{M} = \exp\left(-kt^n\right) * \left(M_o - M_e\right) + M_e \tag{4.7}$$

where k is given Equation (4.5).

4.1.2 SHARAF-ELDEEN THIN-LAYER MODEL

A different model to simulate thin-layer drying of ear corn was developed by Sharaf-Eldeen et al. (1980). The model is a two-term model and incorporates two coefficients, A and B. The form of the two-term model is:

$$\frac{\overline{M} - M_e}{M_o - M_e} = Ae^{-k_{sh}t} + (1 - A)e^{-Bk_{sh}t} \tag{4.8}$$

The value of the drying constant, k_{sh}, in the Sharaf-Eldeen thin-layer equation was calculated using Equation (4.2). To find the coefficients for Equation (4.5), Sharaf-Eldeen plotted the drying parameter versus the initial moisture content for three different air temperatures and relative humidities. By least squares fitting of Equations (4.3) and (4.4) to the experimental data, Sharaf-Eldeen et al. (1980) reported the following equation:

$$k_{sh} = \exp\left[6.8 + \left(0.0195 T_{abs} - 9.75\right) M_o - \left(\frac{2619}{T_{abs}}\right)\right] \tag{4.9}$$

A comparison of Equations (4.5) and (4.6) versus Equations (4.8) and (4.9) will be made in Chapter 5.

4.1.3 EQUILIBRIUM MOISTURE CONTENT

In the calculation of the moisture ratio, knowledge of the equilibrium moisture content is essential. The equation for equilibrium moisture content of ear corn used in Equations (4.1) and (4.8) was derived by Sharaf-Eldeen as discussed in Chapter 2. It has the form:

$$M_e = 5.69\left[\frac{-\ln\left(1 - r.h.\right)}{T_{abs}}\right]^{0.55} \tag{4.10}$$

The validation of the equilibrium moisture content equation will be given in Chapter 5.

4.2 EAR-KERNEL MOISTURE RELATIONSHIPS

It was shown by Schmidt (1948) that there is a relationship between the kernel moisture content and the ear (cob and kernels) moisture content. The relationship shown by Schmidt was used to develop an equation to convert the field data (kernel moisture content) to the same form as the laboratory data (ear moisture content). Pairs of ear and kernel moisture contents (n = 8) were read from the graph of Schmidt (1948), and polynomial regression (R^2 = 09996) yielded the following equation:

$$MC_{Ear} = -0.0002MC_{Kernel}^3 + 0.0196MC_{Kernel}^2 + 0.8334MC_{Kernel} - 0.5675 \qquad (4.11)$$

which was used to relate kernel moisture content (%, d.b.) to total ear (cob and kernels) moisture content (%, d.b.).

4.3 PSYCHROMETRICS

To correctly model the drying process, it is necessary to model the psychrometric relationships. The air properties that affect the drying process include: relative humidity, humidity ratio, vapor pressure, dry-bulb temperature, wet-bulb temperature, specific volume, and enthalpy (Brooker et al., 1992). There are two ways to establish the psychrometric properties of air: 1) psychrometric charts, and 2) psychrometric equations.

For simple calculations that require psychrometric properties, a psychrometric chart can be used if two independent air properties are known. For the computer simulation of deep-bed grain drying, it is not possible to use psychrometric charts. For this reason, a computer program to calculate psychrometric properties was developed by Lerew (1972). The following sections will provide a short description of the importance of each of the psychrometric properties and the associated equations in SI units. It should be noted that the equation constants reported in Brooker et al. (1992) are only given to three decimal places. Therefore, a more accurate psychrometric model was developed, based on values published in ASAE Standards (2000, c), for use in the deep-bed ear-corn drying simulation model.

4.3.1 RELATIVE HUMIDITY

Relative humidity is the ratio of the water vapor pressure in air to the saturated water vapor pressure at the same temperature. It is particularly important in the calculation of the equilibrium moisture content (Brooker et al., 1992).

$$\phi = \frac{P_v}{P_{vs}} \tag{4.12}$$

4.3.2 HUMIDITY RATIO

Also known as absolute humidity or specific humidity, the humidity ratio (W) is the mass of water vapor per unit mass of dry air. This value is used to determine the relative humidity of the drying air, as well as the values associated with relative humidity (Brooker et al., 1992).

$$W = 0.622\left(\frac{\phi P_{vs}}{P_{atm} - (\phi P_{vs})}\right) \tag{4.13}$$

4.3.3 VAPOR PRESSURE

Vapor pressure (P_v) is the partial pressure exerted by the water vapor molecules in moist air. Vapor pressure in air fully saturated with water vapor is known as the saturation vapor pressure. The P_v values are used in the calculation of the relative humidity when given certain input values (Brooker et al., 1992). The equation presented is for saturation vapor pressure (P_{vs}). Calculation of the vapor pressure (P_v) is discussed in Section 4.4.8.

$$P_{vs} = R * \exp\left(\frac{(A + T*(B + T*(C + T*(D + T*E))))}{(T*(F - G*T))}\right) \quad (4.14)$$

Where

$273 < T \text{ (Kelvin)} < 533$

R = 2.2105847380E+07

A = $-2.740552583610 \times 10^{4}$

B = $9.754129373 \times 10^{1}$

C = $-1.46244044 \times 10^{-1}$

D = $1.255753189 \times 10^{-4}$

E = -4.85017×10^{-8}

F = $4.349028978 \times 10^{0}$

G = $3.938107171 \times 10^{-3}$

4.3.4 DRY-BULB TEMPERATURE

Dry-bulb temperature (T_{db}) is the temperature shown on a normal thermometer in air. This value, along with the wet-bulb temperature, is used to easily determine other air properties with the psychrometric relationships

(Brooker et al., 1992). Dry-bulb temperature is a measured value in ear corn drying, and therefore no equation will be presented.

4.3.5 WET-BULB TEMPERATURE

Wet-bulb temperature (T_{wb}) is the steady-state temperature of air indicated by a thermometer with a wet wick covering the bulb in a psychrometer in a moving air stream. This temperature, along with the dry-bulb temperature, is used to calculate other air properties using the psychrometric relationships (Brooker et al., 1992). Similar to dry-bulb temperature, wet-bulb temperature is a measured value in ear corn drying. However, there is an equation to calculate the wet-bulb temperature:

$$T_{wb} = \frac{1}{B'}\left(P_{vswb} - P_v\right) + T_{abs} \tag{4.15}$$

where

$$B' = \frac{1006.9254\left(P_{vswb} - P_{atm}\right)\left(1 + 0.15577 P_v / P_{atm}\right)}{0.62194 h_{fg}} \tag{4.16}$$

4.3.6 SPECIFIC VOLUME

Specific volume (υ) is the volume per unit mass of dry air. This value affects the amount of power required for the fan on a drying system. Specific density is the reciprocal of the specific volume (Brooker et al., 1992).

$$\upsilon = \left(\frac{R_a T_{abs}}{101.325 - \left(\phi p_{vs}\right)}\right) \quad \text{(Lerew, 1972)} \tag{4.17}$$

where

R_a = Gas constant for dry air, 287.09 kg m^2/(s^2 kg K)

4.3.7 ENTHALPY

Enthalpy (h) is the heat content of the moist air per unit mass of dry air above a certain reference temperature. Reference temperature is generally inconsequential, because the difference in enthalpy is the usual value of interest. In grain drying, the latent heat of vaporization, h_{fg}, is the enthalpy value of importance. This value is used in determining the burner size in a given drying system (Brooker et al., 1992).

$$h_{fg} = 2502535.259 - 2385.76424(T_{abs} - 273.16) \qquad (4.18)$$

4.3.8 RELATIVE AND ABSOLUTE HUMIDITY CALCULATIONS

Due to the nature of the data collected on deep-bed ear-corn drying, it is necessary to be able to calculate the relative humidity and absolute humidity of the drying air given the dry-bulb and wet-bulb temperatures.

The calculation of relative humidity begins by solving Equation (4.13) using dry-bulb temperature and wet-bulb temperature. Equations (4.14) and (4.15) are then solved for vapor pressure:

$$P_v = \frac{P_{vswb}\left[0.621974(h_{fg})P_{atm}\right] - \left[1006.9254(P_{vswb} - P_{atm})(T_{wb} - T_{db})\right]P_{atm}}{\left(0.62194(h_{fg})P_{atm}\right) + 0.15577\left[1006.9254(P_{vswb} - P_{atm})(T_{wb} - T_{db})\right]} \qquad (4.19)$$

For ease of calculation, Equation (4.18) is broken down using three simplified equations; A, B, and C.

$A = P_{vswb}$ (4.19a)

$B = 0.62194(H_{fg})\ P_{atm}$ (4.19b)

$C = 1006.9254(P_{vswb} - P_{atm})(T_{wb} - T_{db})$ (4.19c)

The resulting equation for P_v becomes:

$$P_v = \frac{AB - CP_{atm}}{B + 0.15577C} \tag{4.20}$$

The relative humidity is calculated using Equation (4.12) and the absolute humidity using Equation (4.13). Table 4.1 shows the spreadsheet setup to calculate the relative humidity and absolute humidity (values chosen are arbitrary).

A modified FORTRAN program based on the model of Lerew (1972) has been developed by the author to calculate psychrometric properties with either the dry-bulb and wet-bulb temperatures or the dry-bulb temperature and relative humidity. Syntax for the program can be found in Appendix B.

Table 4.1 Verification of psychrometric equations for relative humidity given wet-bulb and dry-bulb temperature.

Constants for Saturation Pressure	
	SI units
R=	2.2105847380E+07
A=	-2.740552583610E+04
B=	9.754129373E+01
C=	-0.146244044
D=	1.255753189E-04
E=	-4.85017E-08
F=	4.349028978E+00
G=	3.938107171E-03
h_{fg} (J/Kg)=	2445542.002
P_{vswb} (Pa)=	2962.94598499519
P_{vsdb} (Pa)=	7594.91850220345
P_v (Pa)=	1874.517876
R.H. =	24.6812112 %
Abs. Hum. =	0.011722041

Enter Temperature (Deg F) Below			
Temp	Deg F	Deg C	Kelvin
Wet-Bulb	75.00	23.89	297.05
Dry-Bulb	105.00	40.56	313.72

These variables are used in the calculation of P_v. Taken from L.E. Lerew, 1972			
A=	P_{vswb}	=	2962.945985
B=	$f(h_{fg}, P_{atm})$	=	1.54113E+11
C=	$f(A, P_{atm}, T_{wb}, T_{db})$	=	1650720843
P_v =	$f(A, B, C, P_{atm})$	=	1874.517876

4.4 APPLICATION AND IMPLEMENTATION OF THE THIN-LAYER MODEL INTO THE DEEP-BED MODEL

Four partial differential equations are used in the simulation of deep-bed ear -corn drying (Bakker-Arkema et al., 1974):

1) air temperature – air temperature at any location
2) ear corn temperature – ear corn temperature at any time
3) air humidity – air humidity at any location
4) ear corn moisture – ear corn moisture content at any time (Section 4.1)

The system of four equations cannot be solved analytically. A numerical solution technique, such as finite differences or finite elements must be used (Brooker et al., 1992). The focus of this thesis is the thin-layer model for ear corn moisture content. For this research project, the deep-bed simulation model was co-developed with a fellow student, and was based on the MSU deep-bed drying model (Islam, 2002, a).

To simultaneously solve the partial differential equations for deep-bed drying, it is assumed that the bed can be modeled as a series of thin layers. Within short time periods (Δt), the air and corn temperature and the air and corn moisture content are assumed to be constant in thin layers (Δx) of the ear corn. When the layers form a deep bed, the output values from one layer – air humidity ratio and air temperature – become the input values for the next layer. The model generates output for the average moisture content, air and corn temperature, and air humidity for all of the layers at a particular time step. Figure 4.1 shows a thin-layer within the deep bed.

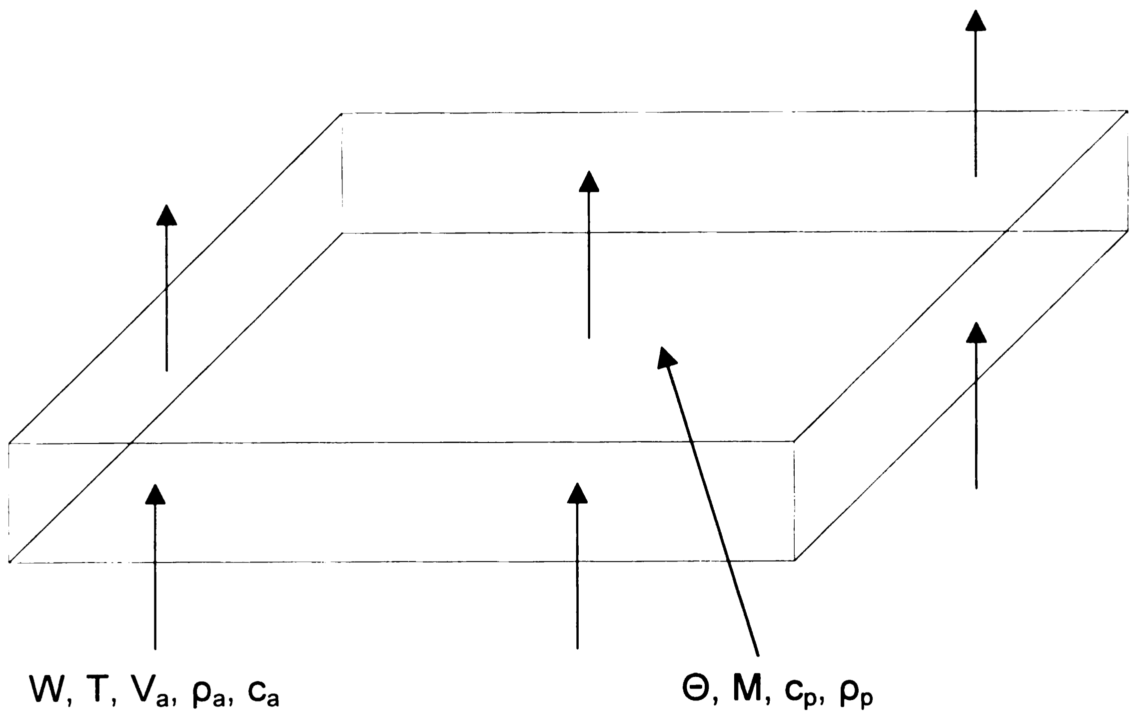

Figure 4.1 Example of thin-layer in a deep-bed simulation model
(Adapted from Brooker et al., 1992).

The deep-bed model was implemented via FORTRAN. This was done for continuity, because the original MSU drying models (Bakker-Arkema et al., 1974) were written using FORTRAN. Figure 4.2 shows the flow diagram of the deep-bed, ear-corn drying simulation model. Appendix B contains the FORTRAN code for the psychrometric properties of air, the equilibrium moisture content of ear corn, and the new thin-layer model, including the drying parameter (k), described in Chapter 5. The complete ear-corn drying simulation model can be found in the Ph.D. Dissertation of Md. Taufiqul Islam (Islam, 2002, b).

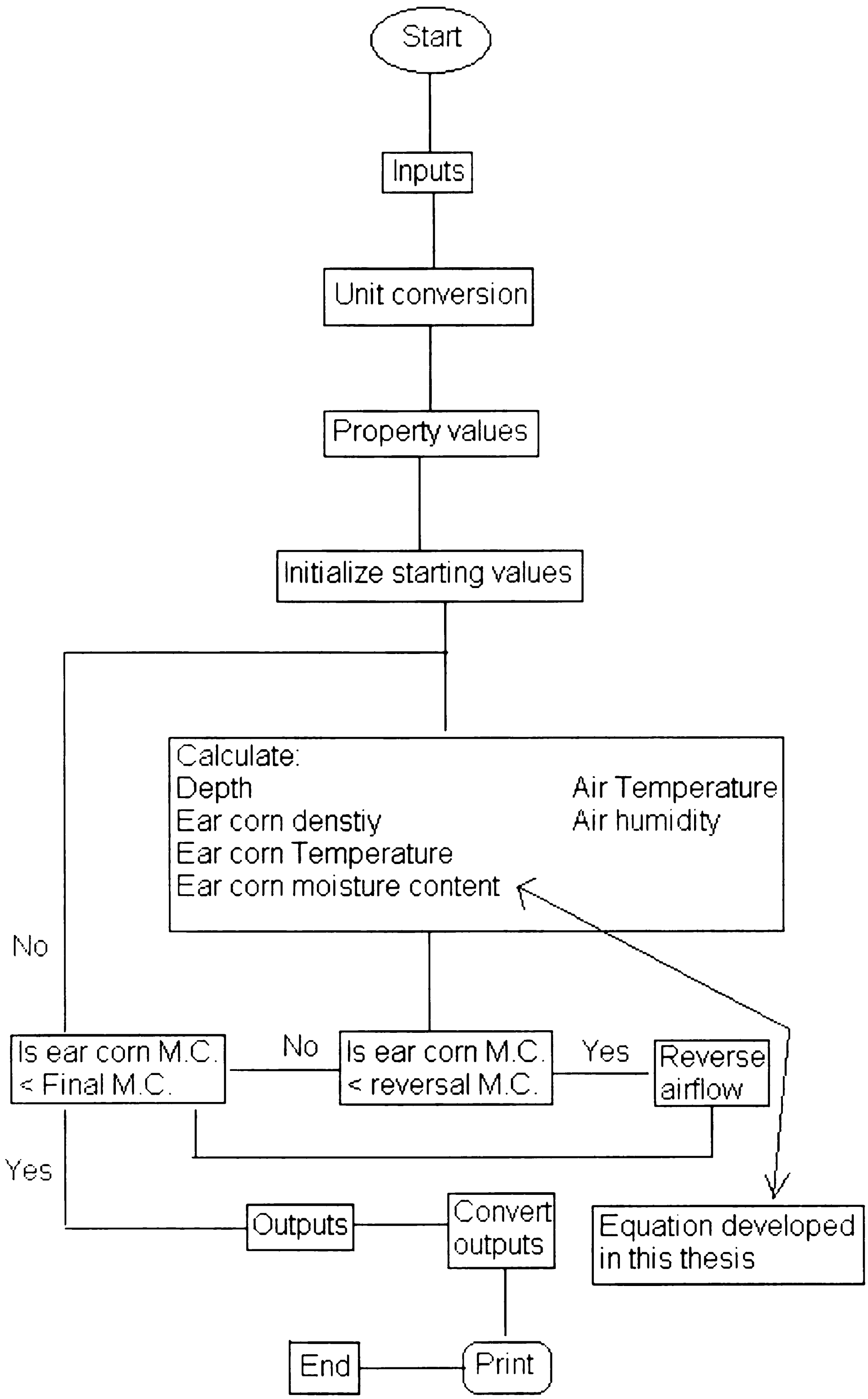

Figure 4.2 Flow diagram of deep-bed ear-corn drying simulation model.

CHAPTER 5

RESULTS AND DISCUSSION

Experimental data were collected from both laboratory tests and field tests. Laboratory experiments included equilibrium moisture content, thin-layer, and individual kernel moisture content tests. Field experiments consisted of the collection of moisture content data during deep-bed, ear-corn drying.

5.1 LABORATORY EXPERIMENTS

5.1.1 EQUILIBRIUM MOISTURE CONTENT

Laboratory data for the equilibrium moisture content were taken to validate the equation for equilibrium moisture content derived by Sharaf-Eldeen (1980) (Equation [4.10]). To measure equilibrium moisture content, samples were allowed to dry until weight loss was negligible. At this time, the samples were considered to be at equilibrium moisture content. During drying, the relative humidity and temperature in the laboratory and oven were recorded. Table 5.1 shows a comparison of the experimental equilibrium moisture content values and the equilibrium moisture content values predicted by Equation (4.10). The root mean squared error (RMSE) value is 0.54. Therefore, the prediction model predicted the equilibrium moisture content at 40°C to within ± 0.54 d.b. %[1].

[1] Moisture contents in this Chapter are reported in percent dry basis, because dry basis is generally used in engineering calculations (CIGR Handbook of Agricultural Engineering, Vol. 4, 1999).

Table 5.1 Comparison of experimental and predicted equilibrium moisture contents at 40°C.

Experimental EMC (%, d.b.)	Predicted EMC (%, d.b.)	Difference (%)	Difference Squared
6.8	7.6	-0.8	0.64
8.3	7.6	0.7	0.49
7.6	7.6	0.0	0.00
7.5	7.6	-0.1	0.01
8.4	7.6	0.8	0.64
7.7	7.6	0.1	0.01
7.6	7.6	0.0	0.00
8.5	7.6	0.9	0.81
7.7	7.6	0.1	0.01
5.1	5.6	-0.5	0.25
5.3	5.6	-0.3	0.09
5.3	5.6	-0.3	0.09
6.3	5.5	0.8	0.64
6.0	5.7	0.3	0.09
6.1	5.7	0.4	0.16
5.6	5.7	-0.1	0.01
6.2	5.7	0.5	0.25
5.9	5.7	0.2	0.04
6.5	5.7	0.8	0.64
6.5	5.7	0.8	0.64
		SSE = 5.51	
		MSE = 0.29	
		RMSE = 0.54	

5.1.2 THIN-LAYER TESTS

Complete data from the thin-layer tests can be seen in Appendix A. An illustrative example of the thin-layer data can be seen in Figures 5.1 and 5.2. The samples in Figures 5.1 and 5.2 were dried at 35°C (95°F), 11.4% relative humidity, and initial moisture contents of 38.5 and 38.4% (d.b.), respectively. Samples were also dried at 35, 40, and 45°C (95, 104, and 113°F), in the 5 to

15% relative humidity range at varying initial moisture contents. Initial moisture contents ranged from 28.6 to 60.5% (d.b.).

The equilibrium moisture content was calculated using the laboratory conditions for each test and the psychrometric equations (see Table 5.2). For the tests illustrated in Figure 5.1 and 5.2, the equilibrium moisture content was 7.6% (d.b.). The moisture ratio curve for Ear #1 becomes negative after 80 h of drying; this suggests that the ambient drying conditions (i.e., the relative humidity) may have varied slightly at the end of the drying cycle, causing the equilibrium moisture content to fluctuate, or, more likely, the EMC equation was simply not accurate for that particular ear of corn.

Table 5.2 Calculation of the equilibrium moisture content using laboratory conditions, psychrometric equations, and Equation (4.10).

Known:

Laboratory Temperature	Laboratory r.h.	Oven Temperature
22.7 °C	24.1%	35.8°C

Using the Lerew Psychrometric Program

Inputs		Output	
Temperature	22.7°C	Humidity ratio	0.00411
r.h.	24.1%		

Inputs		Output	
Temperature	35.8°C	r.h.	11.39%
Humidity ratio	0.00411		

Equilibrium moisture content (Equation [4.10])

Inputs		Output	
Temperature	35.8°C	EMC (%, d.b.)	7.6
r.h.	11.39%		

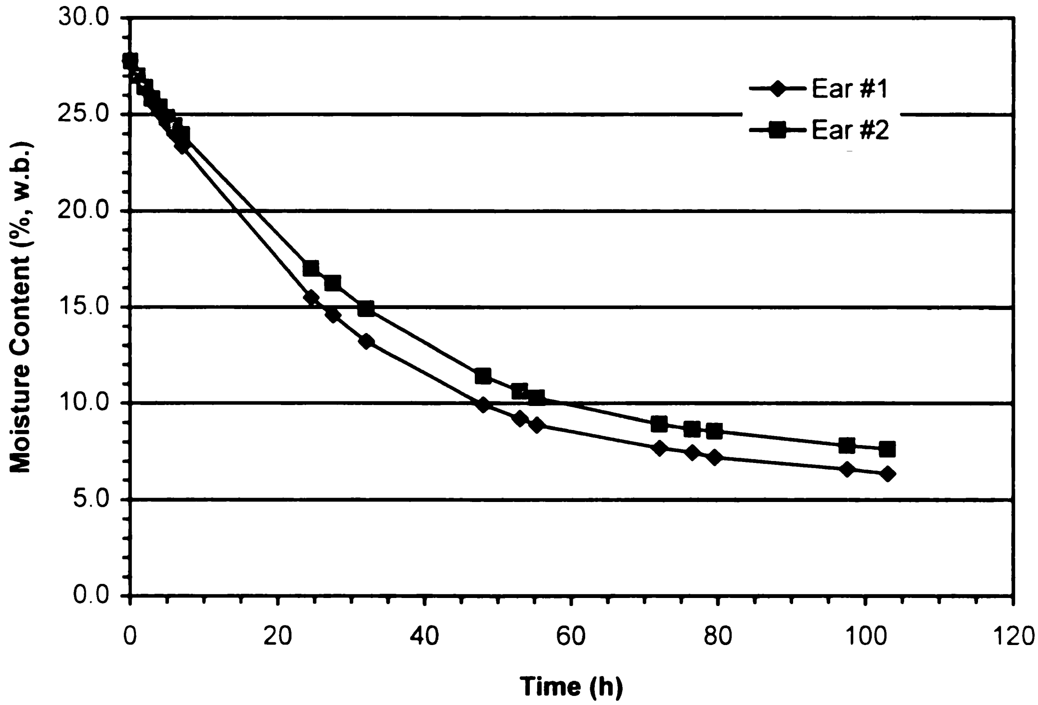

Figure 5.1 Moisture content versus time for two ears of corn dried in the laboratory at 35°C (95°F) and 11.4% relative humidity.

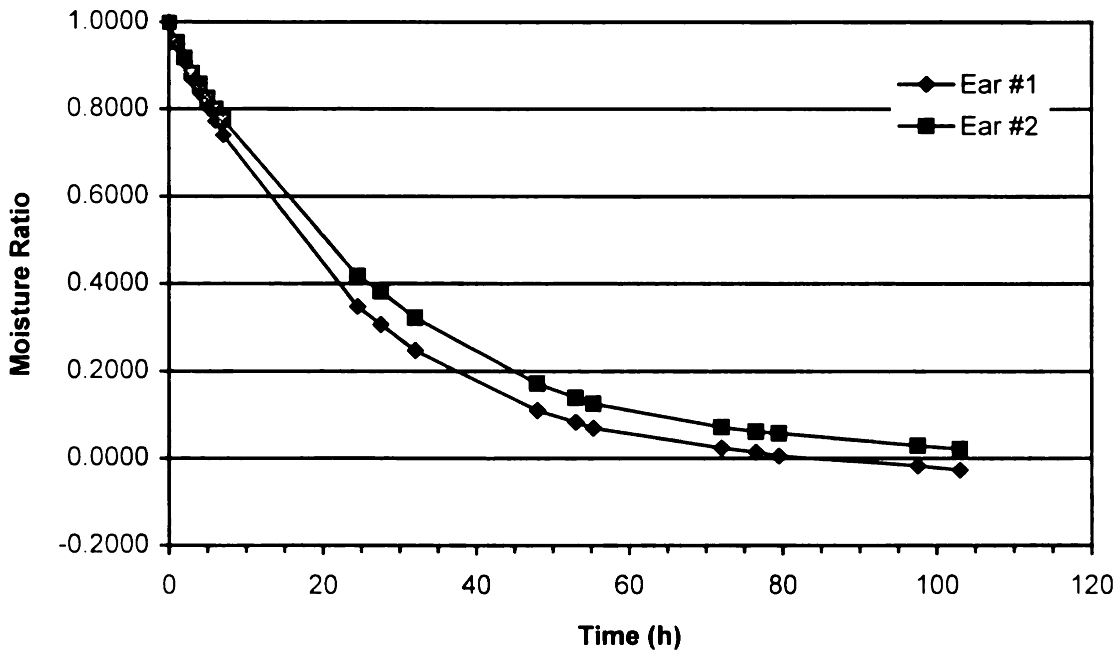

Figure 5.2 Moisture ratio versus time for two ears of corn dried in the laboratory at 35°C (95°F) and 11.4% relative humidity.

Appendix A contains the same drying rate data for all the samples dried in the laboratory. Each sample is labeled with a code number (printed in **bold** on the table). In the laboratory experiments, 65 sets of data were collected. The data sets contain 10 to 20 individual data points (totaling 901 data points), depending on the total drying time of the experiment.

5.1.3 INDIVIDUAL KERNEL MOISTURE CONTENT

Variability in individual kernel moisture content is important. Figures 5.3 and 5.4 show the distribution of moisture content for one ear of corn harvested in 1999. Figure 5.3 shows the average axial kernel moisture content for each row around, from tip to bottom, of one ear of corn. The kernels around the tip and bottom of the ear have lower moisture contents, while the kernels near the middle of the ear have higher moisture contents.

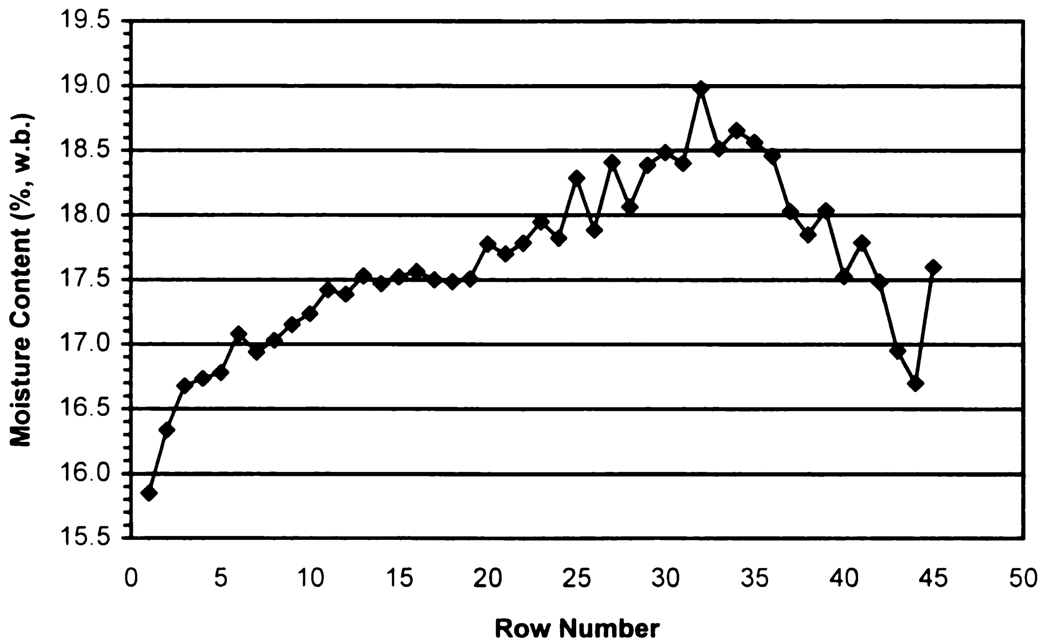

Figure 5.3 Average axial moisture content for each row around one ear of corn.

The radial variation of the average kernel moisture content can be seen in Figure 5.4. The kernels in vertical rows one to eight have lower moisture content then the kernels in rows nine to fourteen.

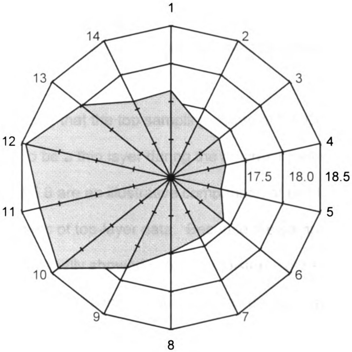

Figure 5.4 Average radial moisture content for each vertical row of kernels on one ear of corn (center point is 16.5%, w.b., outer gridline is 18.5%, w.b.).

This variability shows that care must be taken when determining moisture content. If a limited number of kernels are used to determine moisture content, the moisture content average determined may not reflect the actual average moisture content

5.2 FIELD EXPERIMENTS

Data taken at the Constantine research site were used in the development and validation of the thin-layer drying model. It was hypothesized that the bottom layer of ear corn in the deep-bed dryer could be considered to be a thin layer during the up-air part of drying. Figures 5.5 and 5.6 are an illustrative comparison of two thin-layer experiments to two sets of data taken at the bottom of the drying bin.

It was hypothesized that the top sampling points of the Constantine data can also be considered to be a thin layer during the down-air part of drying.

Figures 5.7 and 5.8 are an illustrative comparison of two thin-layer experiments to two sets of top-layer data. Because the sampling points on the top of the drying bed usually showed different moisture contents due to varying drying conditions (e.g., air channeling during up-air drying), each sampling point was used individually for comparison in thin-layer modeling.

Based on the above comparisons, the field data were included in the calibration and validation data sets. After the thin-layer model is described this assumption will tested by evaluating whether there is a significant bias between the two types of data (i.e., laboratory data and field data).

Appendix A contains the complete set of field data included in the entire data set. Each data set is labeled with a code number and, in the case of the down-air samples, a location number (both printed in **bold** on the upper left-hand side and right-hand side, respectively, in the data tables). Field data includes the drying-air temperature for each data point. In the nonlinear regression analysis, the average temperature for each portion of the drying cycle was used.

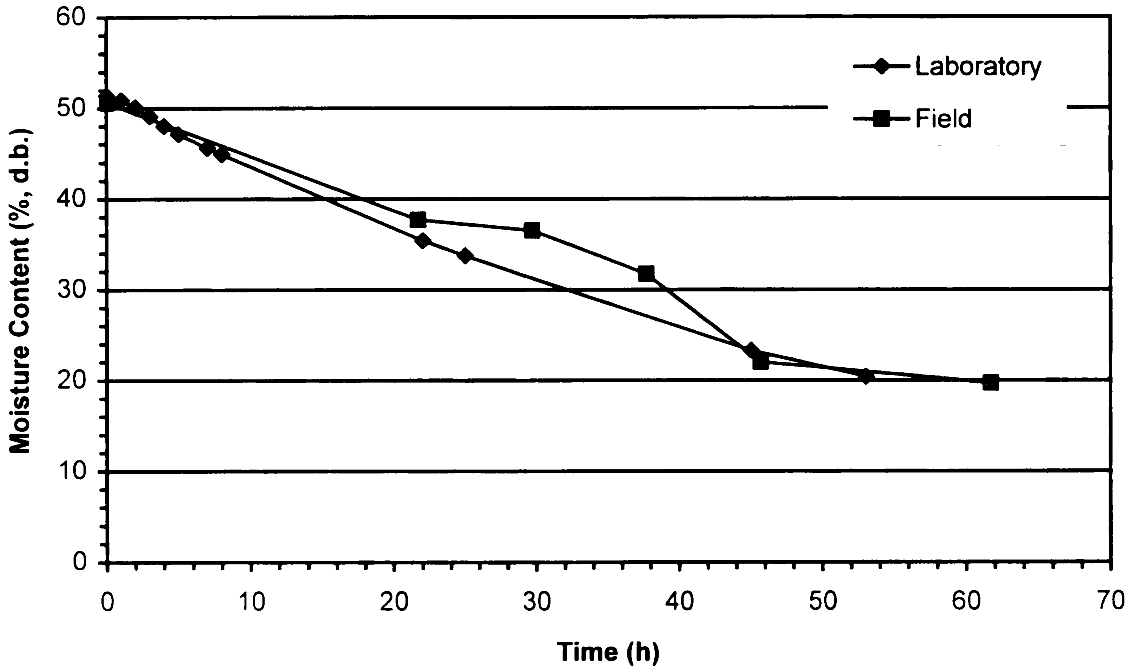

Figure 5.5 Moisture content versus time for field up-air bottom-layer data (37.5°C [99.5°F], 34.72% relative humidity) and thin-layer laboratory data (40°C [104°F], 24.3% relative humidity).

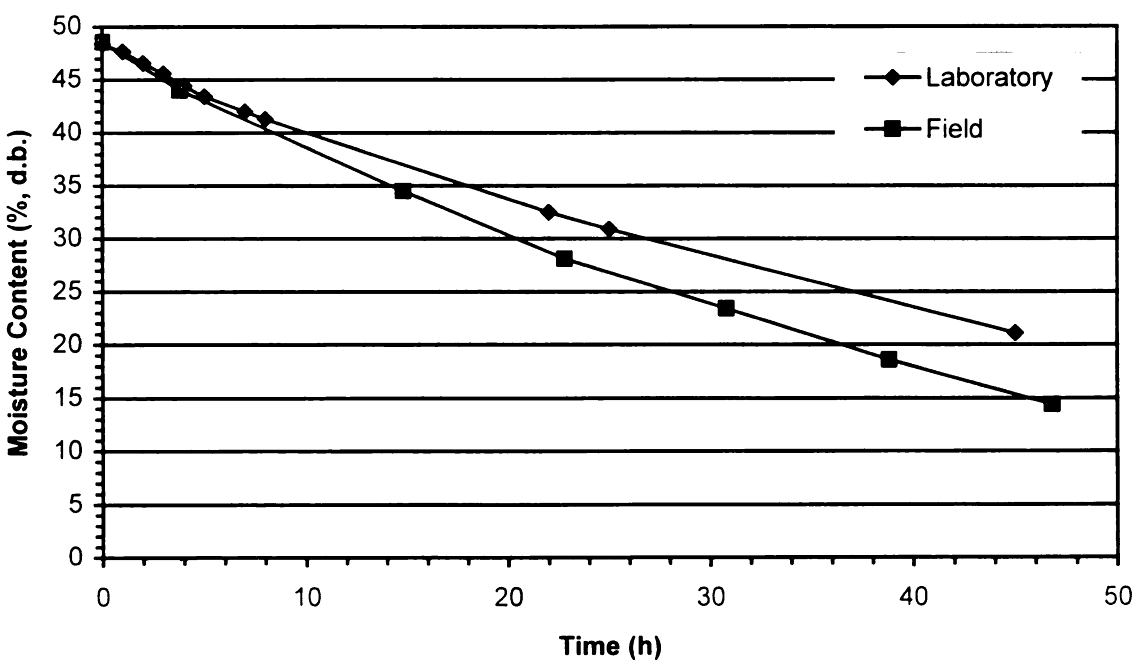

Figure 5.6 Moisture content versus time for field up-air bottom-layer data (37.9°C [100.2°F], 34.89% relative humidity) and thin-layer laboratory data (40°C [104°F], 24.3% relative humidity).

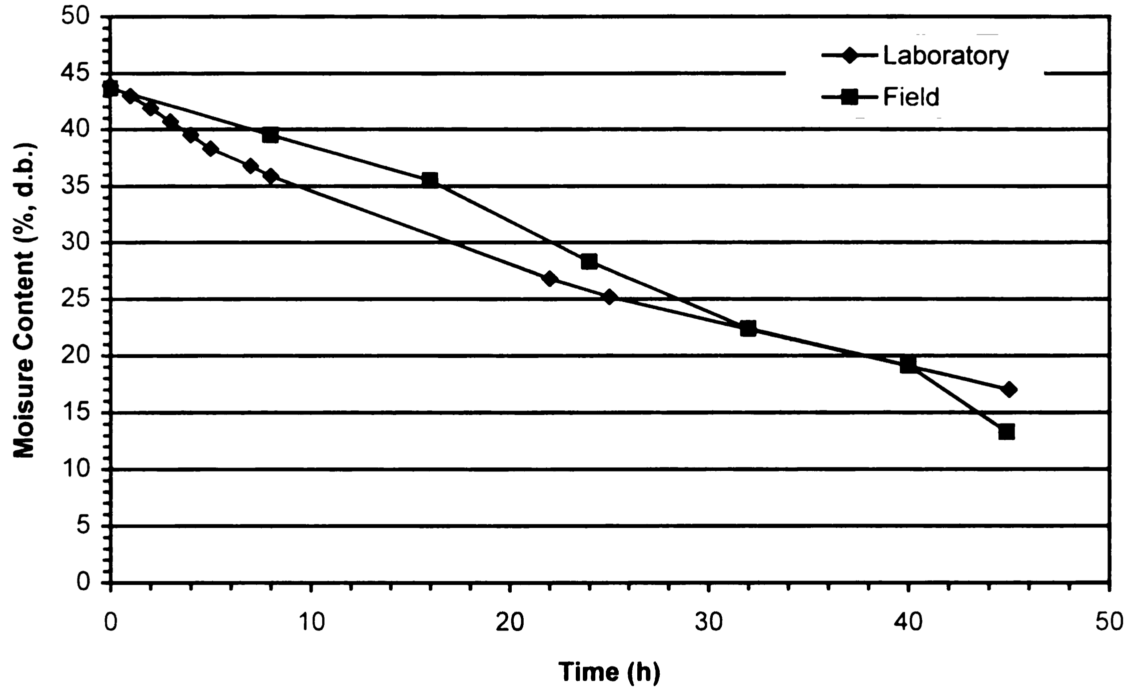

Figure 5.7 Moisture content versus time for field down-air top-layer data (39.4°C [102.9°F], 11.62% relative humidity) and thin-layer laboratory data (40°C [104°F], 24.3% relative humidity).

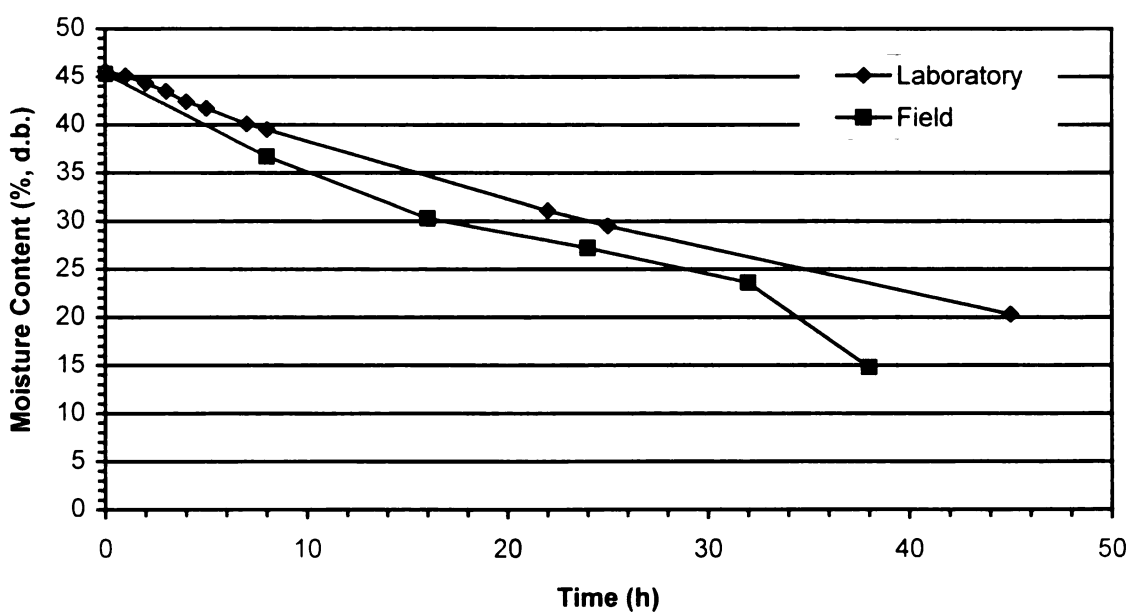

Figure 5.8 Moisture content versus time for field down-air top-layer data (41.3°C ([106.4°F], 16.17% relative humidity) and thin-layer laboratory data (40°C [104°F], 24.3% relative humidity).

5.3 REGRESSION RESULTS

5.3.1 NONLINEAR REGRESSION

The complete set of calibration data (n_{sets}=127, n_{points}=1,206) was imported to a JMP worksheet along with Equation (4.6). Table 5.3 shows an example of the drying data used for the nonlinear regression. The Nonlinear Fit Platform (nonlinear regression user interface in JMP) using second derivatives was employed to solve for the coefficients A, B, C, D, and n. This procedure used the Newton-Raphson method (JMP Statistics and Graphics Guide, Version 4, 2001).

Table 5.3 Example of drying data at 40°C (104°F) and 24.3% relative humidity.

Code	Drying Time (hr)	Moisture Ratio	Initial M.C. (%)	Temp. (K)
1	0	1.0000	45.6	313.0
1	1	0.9855	45.6	313.0
1	2	0.9662	45.6	313.0
1	3	0.9444	45.6	313.0
1	4	0.9154	45.6	313.0
1	5	0.8961	45.6	313.0
1	7	0.8550	45.6	313.0
1	8	0.8405	45.6	313.0
1	22	0.6206	45.6	313.0
1	25	0.5796	45.6	313.0
1	45	0.3403	45.6	313.0
1	53	0.2461	45.6	313.0
1	72	0.1470	45.6	313.0
1	94	0.0673	45.6	313.0

Eighty iterations were required by the JMP software to converge to the following values for the parameters in Equation (4.6):

A → -28.66

B → 7947

C → 0.2744

D → -86.00322

n → 0.9915

Figure 5.9 shows the JMP output for nonlinear regression to solve for the parameter values. RMSE is the standard deviation of the residual error when comparing the model-predicted values to the experimental values; it is also called the standard error of calibration (SEC). The RMSE will be compared to the standard error of prediction (SEP) for validation purposes. The SEP is calculated using the independent validation set in the same manner the RMSE is calculated for the calibration data set:

$$SEP = RMSE = \sqrt{\frac{\sum\left(x_i - x_j\right)^2}{(n-1)}} \tag{5.1}$$

The value of the RMSE for the complete calibration data set is 0.08185. This means that when using the prediction model to determine moisture ratio values, the average expected error of the model is ±0.08185. With moisture ratios ranging from one to zero, this is approximately an 8% error. In the case of Figure 5.9, the SSE is 8.04615. As the RMSE, SSE, and MSE get smaller, the predictive equation for moisture ratio is more closely modeling the experimental data.

Nonlinear Fit

Control Panel

Stopped

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	79	100
Shortening	0	15
Obj Change	7.1126013e-9	0.0000001
Prm Change	0.0002846137	0.0000001
Gradient	5.7243284e-8	0.000001

Parameter	Current Value	Lock
A	-28.65590333	
B	7946.8012548	
C	0.2743851787	
D	-86.00322229	
n	0.9915435211	

SSE 8.0461462781

N 1206

Edit Alpha	0.050
Convergence Criterion	0.05
Goal SSE for CL	.

Solution

SSE	DFE	MSE	RMSE
8.0461462781	1201	0.0066995	0.0818507

Parameter	Estimate	ApproxStdErr	Lower CL	Upper CL
A	-28.65590333	5.13113055	.	.
B	7946.8012548	1604.66594	.	.
C	0.2743851787	0.03791906	.	.
D	-86.00322229	11.8607088	.	.
n	0.9915435211	0.01379777	.	.

Figure 5.9 JMP output for the parameter values of Equation (4.6).

A plot of the experimental values versus the predicted values (Equation [4.6]) for the calibration data set (n_{sets}=127, n_{points}=1,206) shows the relationship for the moisture ratio (Figure 5.10). The scatter plot has a high R^2 (0.947). Further analysis on the outliers and their effect on the predictive model will be discussed later in this section.

After the values for the equation parameters were determined, the prediction of the k-value was examined. In order for the model to predict moisture ratio and moisture content properly, the drying parameter (k) must increase as temperature increases for a particular initial moisture content. Figure 5.11 shows the relationship between the temperature and the k-value at an initial moisture content 42.9% (d.b) (30%, w.b.).

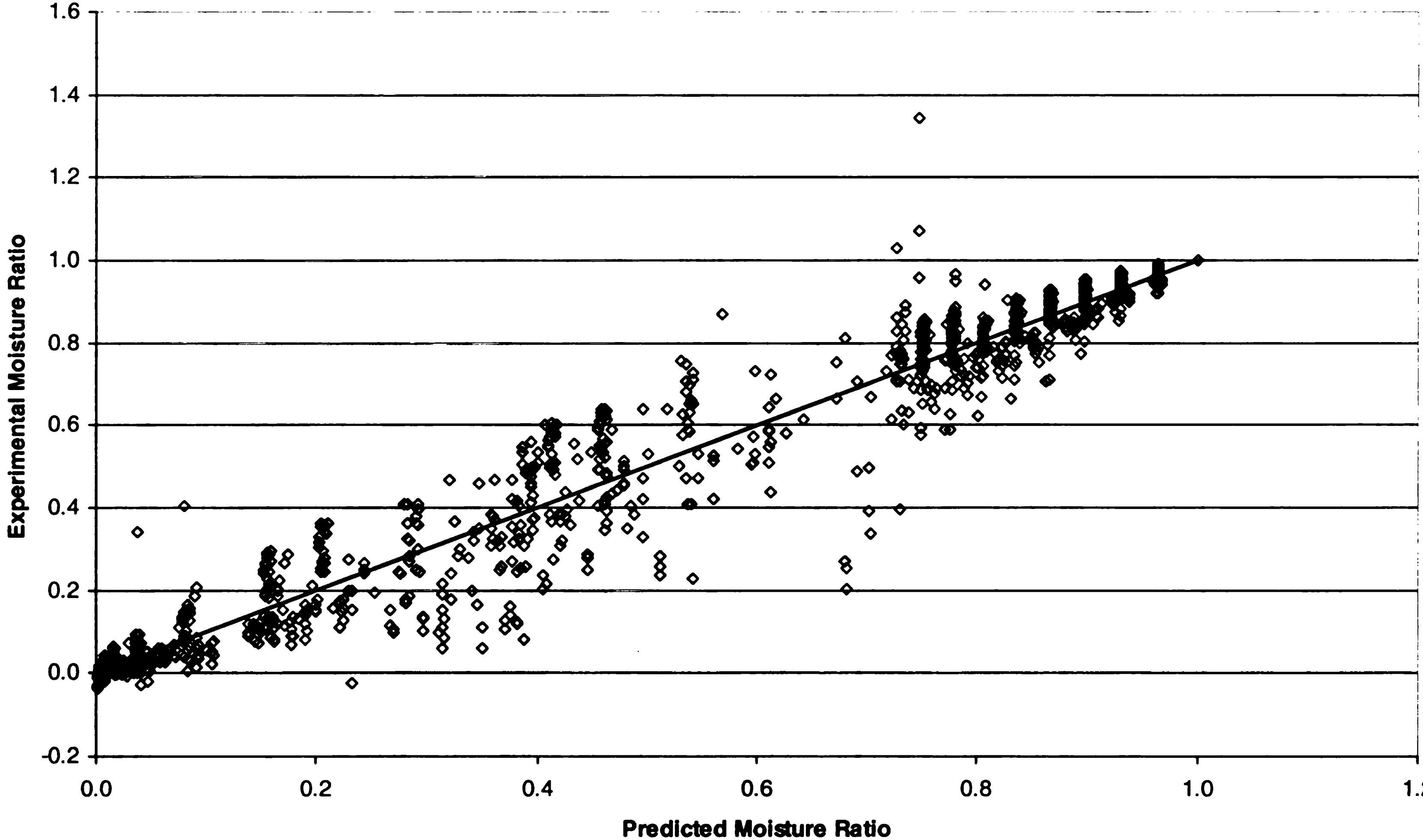

Figure 5.10 Experimental moisture ratio versus predicted moisture ratio for 1,206 data points.

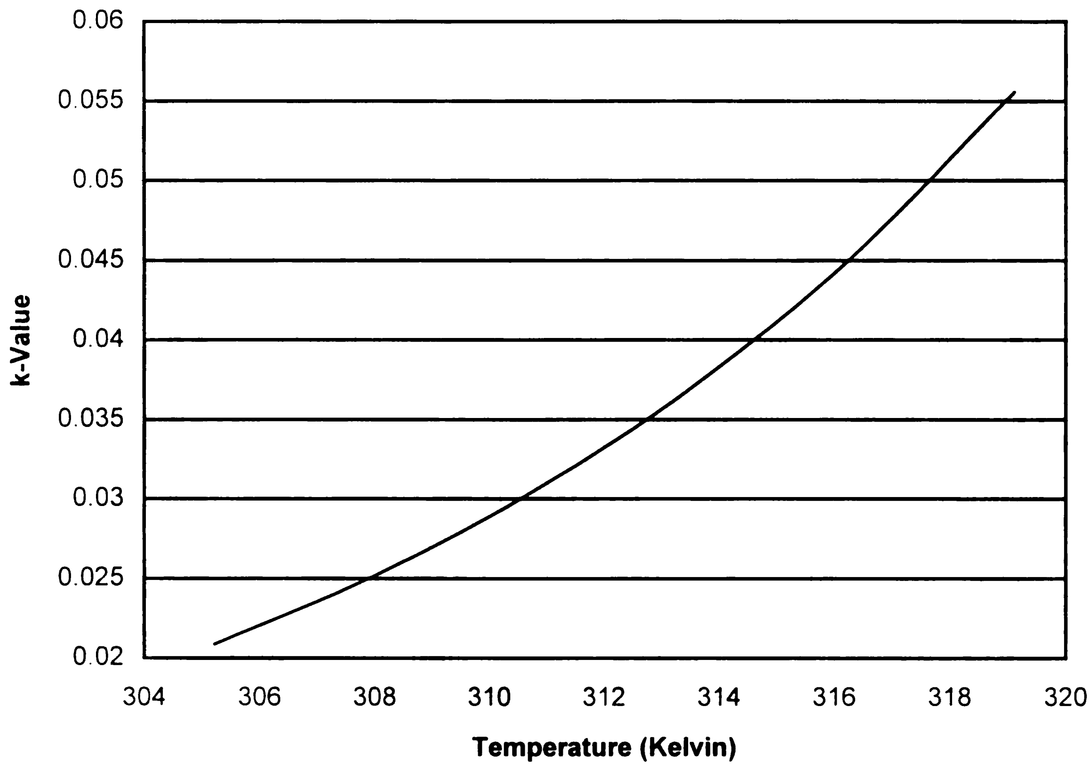

Figure 5.11 k-value versus temperature for Equation (4.5) at 42.9% (d.b.) initial moisture content.

The SEP values for the moisture ratio and moisture content were calculated using the 30 data sets removed for validation (n_{points}=152). For each data set, the corresponding drying conditions were used to calculate the k-value and the equilibrium moisture content. Equation (4.6), with the parameters estimated from the calibration data set, was used to calculate the predicted moisture content for each data point in the validation set, and subsequently this value was compared to the experimental moisture content. The SEP for the moisture content was 3.8% (d.b.); the SEP for the moisture ratio was 0.1147. Table 5.4 shows an example of data from the validation set.

Table 5.4 Example of the validation set for moisture content and moisture ratio.

Temp =	110°F	316.3 K			
R.H. =	28.44%				
IMC (w.b.) =	37.7%	d.b=60.6%			
EMC =	13.1%				
k =	0.047209				
Code #	Time (h)	Experimental M.C. (%, d.b.)	Predicted M.C. (%, d.b.)	Difference	Squared
135	0	42.9	42.9	0.0	0.0
135	8	34.0	33.7	0.4	0.1
135	16	26.5	27.4	-0.8	0.7
135	21.65	15.3	24.1	-8.9	78.8
Code #	Time (h)	Experimental MRAT	Predicted MRAT	Difference	Squared
135	0	1.0000	1.0000	0.0000	0.0000
135	8	0.7028	0.6900	0.0128	0.0002
135	16	0.4509	0.4781	-0.0272	0.0007
135	21.65	0.0724	0.3694	-0.2970	0.0882

A further robustness check of the thin-layer equation (Equation [4.6]) is the ratio of SEP divided by SEC for the moisture ratio:

$$\frac{SEP}{SEC} = \frac{0.1147}{0.08185} = 1.4$$

The value of 1.4 reflects good robustness of the model against the independent validation set.

The effect of outliers in the calibration data set was further explored by using the jackknife technique to eliminate outliers (Netter, 1993). The jackknife technique calculates the distance of n data points from the multivariate mean. The distance is calculated using the estimates of the mean, standard deviation, and correlation for n-1 observations. The process is repeated until each data point has been once excluded from the calculations. In this study, data points were deemed outliers if the jackknife distance was greater than 2.5 for the moisture ratio. As a result, 37 data points were removed as outliers and the nonlinear regression was run on the remaining data. The resulting parameter values were:

$A \rightarrow -26.78$

$B \rightarrow 7380$

$C \rightarrow 0.2556$

$D \rightarrow -80.205$

$n \rightarrow 0.9783$

The SEC for the moisture ratio without the outliers reduced to 0.07773. The resulting new parameter estimates, calculated using the modified data, resulted in a SEP of 0.1160 for the moisture ratio and 3.8% (d.b.) for the moisture content. Thus, the value for the SEP/SEC ratio for moisture ratio is 1.49. This shows that the outliers do not have an effect on the data set. The complete validation analysis for the unmodified data and the jackknife-modified data can be found in Appendix A.

Figures 5.12 and 5.13 show the experimental moisture ratio versus the predicted moisture ratio, and the experimental moisture content versus the predicted moisture content, for the unmodified validation data. The R^2 value for the moisture ratio comparison was 0.8491, and for the moisture content data

0.9165. Figures 5.14 and 5.15 show the experimental moisture ratio versus the predicted moisture ratio and the experimental moisture content versus the predicted moisture content for the model based on the jackknife-modified calibration data set, respectively. The R^2 value for the moisture ratio comparison was 0.8457, and for the moisture content data 0.9157. For both the moisture ratio and moisture content, the R^2 values are larger for the unmodified data than for the jackknife-modified data; the unmodified data has a higher correlation.

Using the parameter values calculated with the unmodified data, thin-layer drying Equations (4.5) and (4.6) become:

$$MRAT = \exp(-kt^{0.9915}) \tag{5.2}$$

where

$$k = \exp\left(-28.66(0.2744(T_{abs}) + -86.0032)M_o + \frac{7947}{T_{abs}}\right) \tag{5.3}$$

Thus, Equations (5.2) and (5.3) are the thin-layer drying rate model for ear corn. The parameter values have been validated against independent field data. Subsequently, Equations (5.2) and (5.3) will be incorporated in the deep-bed, ear-corn drying rate program. In the following section, the newly parameterized thin-layer model will be compared to the Sharaf-Eldeen (1980) thin-layer model.

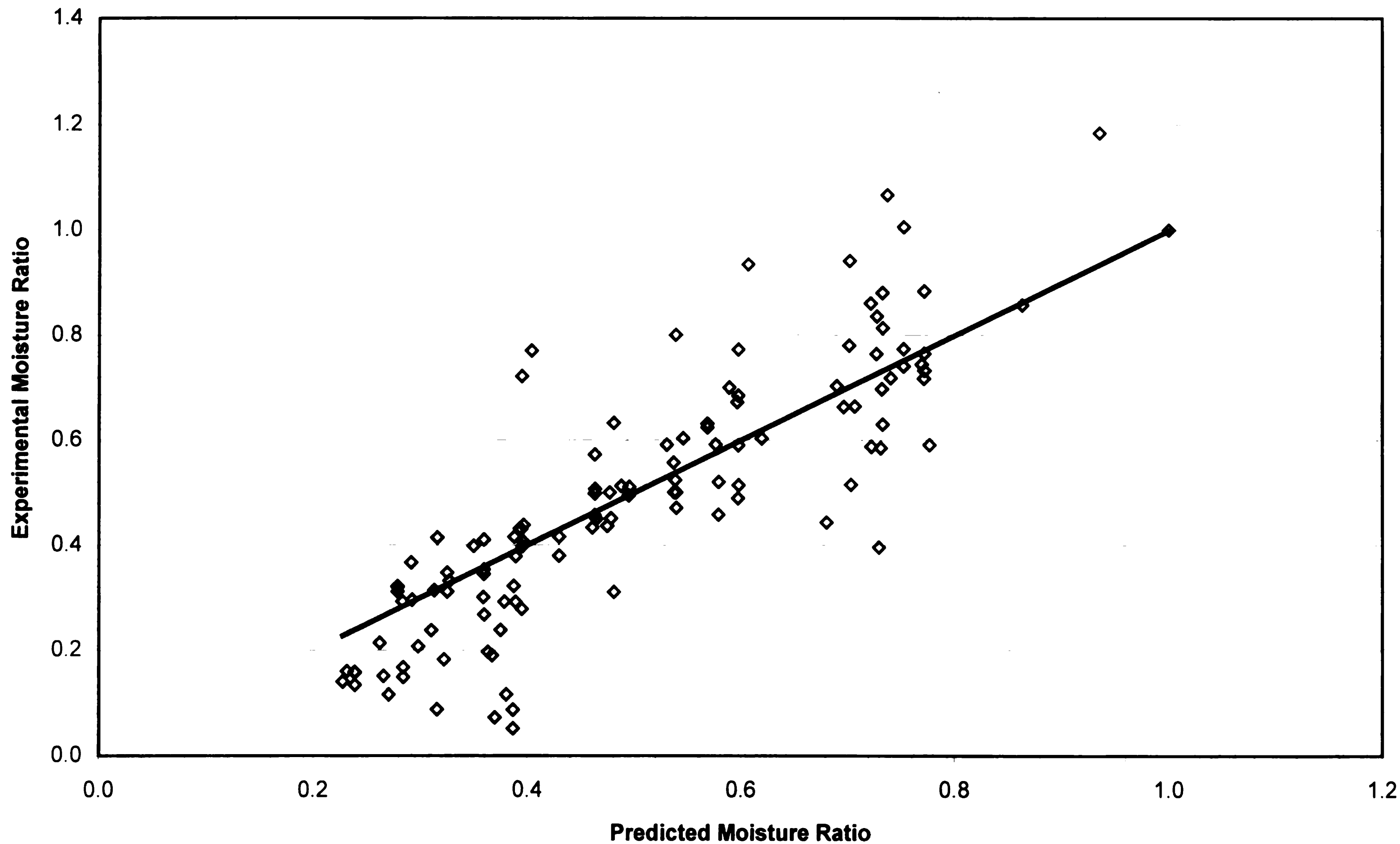

Figure 5.12 Experimental ear-corn moisture ratio versus predicted moisture ratio for the model based on the unmodified calibration data set.

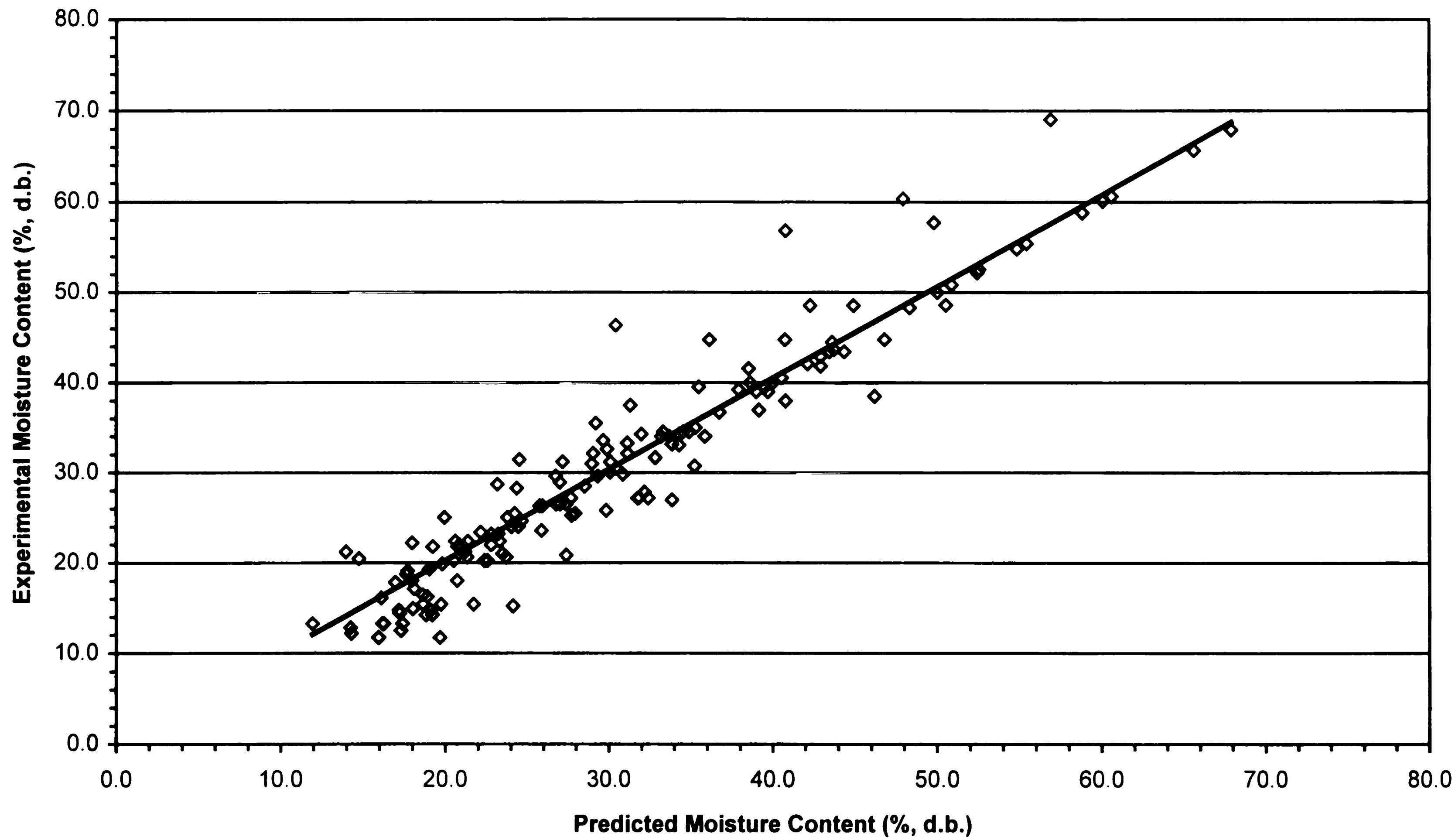

Figure 5.13 Experimental ear-corn moisture content versus predicted moisture content for the model based on the unmodified calibration data set.

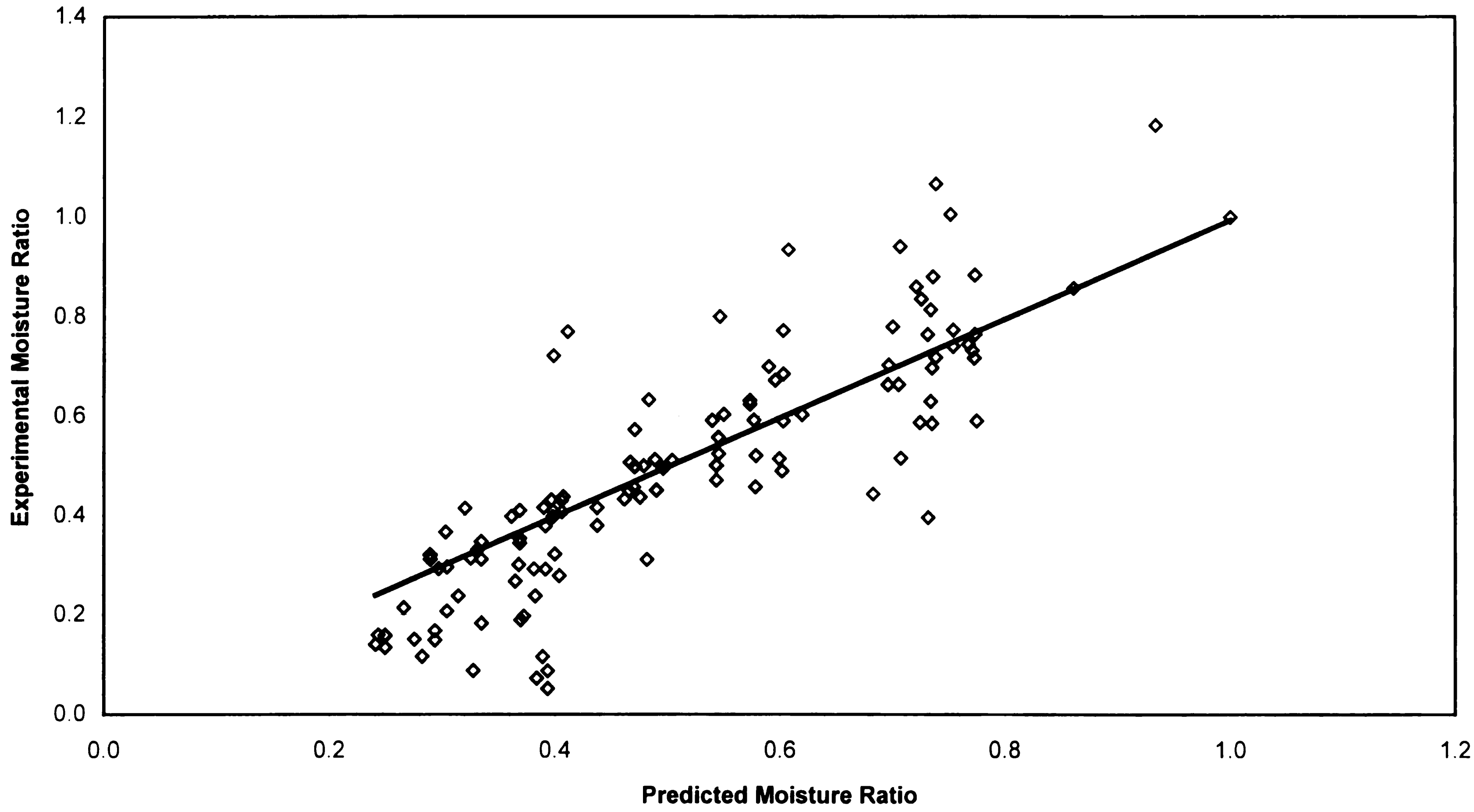

Figure 5.14 Experimental ear-corn moisture ratio versus predicted moisture ratio for the model based on the jackknife-modified calibration data set.

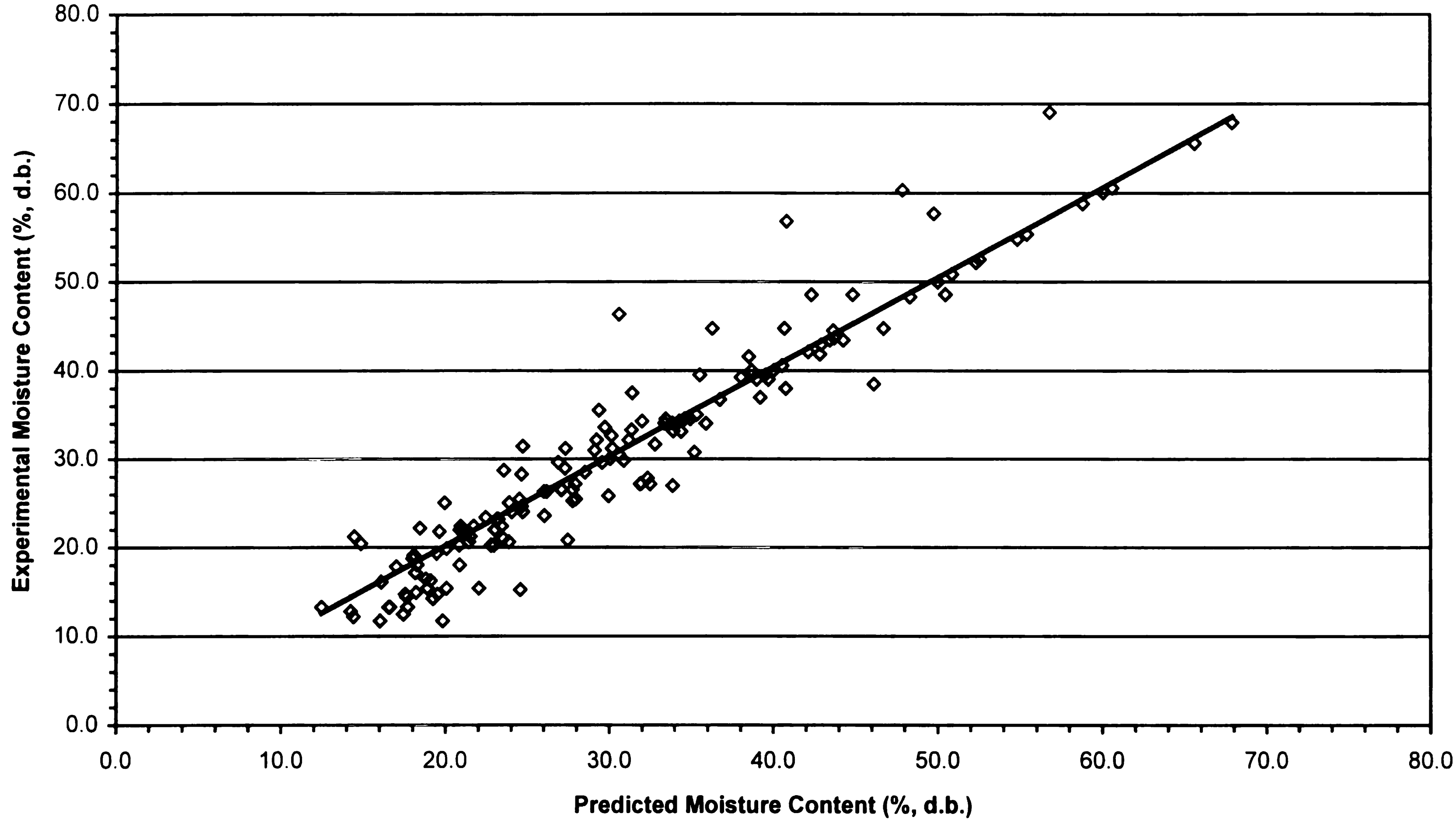

Figure 5.15 Experimental ear-corn moisture content versus predicted moisture content for the model based on the jackknife-modified calibration data set.

5.4 EQUATION COMPARISONS

5.4.1 EXPERIMENTAL DATA AND THE SHARAF MODEL

Comparison of the experimental data from this thesis to the model from Sharaf-Eldeen et al. (1980) indicates poor predictions of moisture ratio and moisture content at times larger than 40 hours (See Figures 5.16 and 5.17). The experimental data shows a more rapid drying rate than predicted by the Sharaf model.

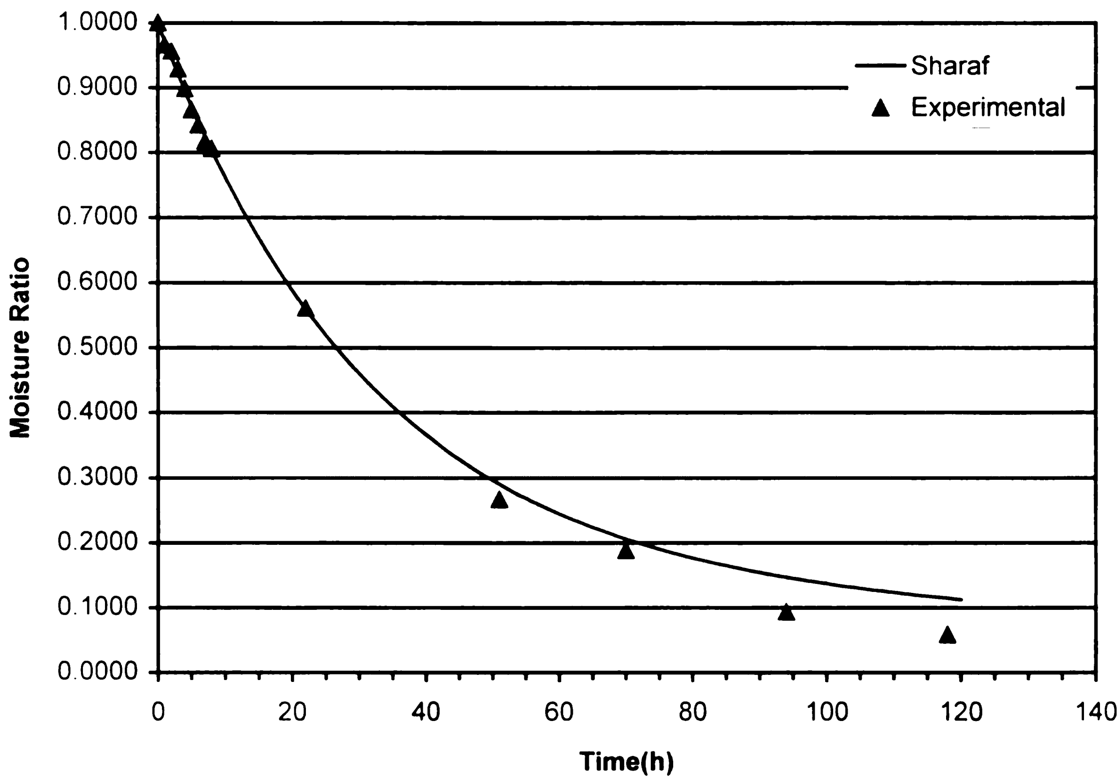

Figure 5.16 Moisture ratio versus time for a comparison of the Sharaf model to experimental data for moisture ratio dried at 40°C and 7% relative humidity.

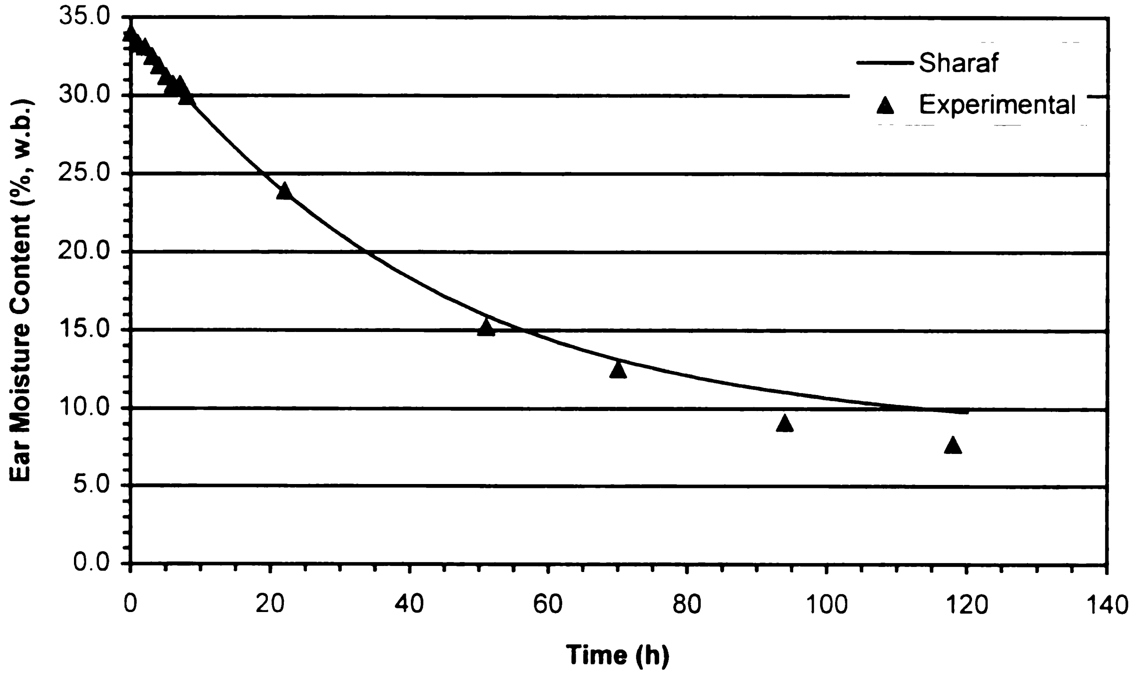

Figure 5.17 Ear moisture content versus time for a comparison of the Sharaf model to the experimental data for moisture content dried at 40°C and 7% relative humidity.

5.4.2 FRIANT AND SHARAF

In this section, the Sharaf model (Sharaf-Eldeen et al., 1980) and the new model are compared to the experimental values. Table 5.5 shows the data in the comparison. The drying conditions – drying-air temperature, drying-air relative humidity, and kernel initial moisture content – are contained in the shaded cells. The equilibrium moisture content for both the Sharaf model and the new model was calculated using Equation (4.10). The constants of the new model[2] are labeled "Friant constants". The constants of the Sharaf Equation are labeled "Sharaf constants."

[2] For ease of comparison, the newly parameterized model is referred to as the Friant model.

Table 5.5 Spreadsheet used to calculate predicted moisture content, moisture ratio, and drying time using the Friant and Sharaf equations.

**All values for moisture content are dry basis unless otherwise stated.

Drying air temperature (Deg. F) =	104	=	40.00	Celsius =	313.00	Kelvin
Drying air relative humidity (%) =	7	=	0.0700	decimal		
Initial kernel moisture content (%, w.b.) =	28.6	=	0.514	Ear M.C., Decimal, d.b.	EMC (w.b.)	
EMC (%, d.b.) =	5.7	=	0.057	decimal, d.b.	5.4	
k (Friant) =	0.035836					
k (Sharaf)=	0.031999					

Sharaf constants	
A=	0.8459
B=	0.1278
Friant constants	
A=	-28.6559
B=	7946.80
C=	0.274385
D=	-86.0032
n=	0.991544

Time	Friant		Sharaf		Ear Moisture Content %, wet basis	
(h)	Ear M.C. (%, d.b.)	Moisture Ratio	Ear M.C. (%, d.b.)	Moisture Ratio	Friant	Sharaf
0	51.4	1.000	51.4	1.0000	34.0	34.0
1	49.8	0.9648	50.2	0.9727	33.2	33.4
2	48.3	0.9312	49.0	0.9463	32.6	32.9
3	46.8	0.8990	47.8	0.9207	31.9	32.3
4	45.4	0.8679	46.6	0.8959	31.2	31.8
5	44.0	0.8380	45.6	0.8718	30.6	31.3
6	42.7	0.8091	44.5	0.8485	29.9	30.8
7	41.4	0.7813	43.5	0.8259	29.3	30.3
8	40.2	0.7545	42.5	0.8040	28.7	29.8
9	39.0	0.7286	41.5	0.7828	28.1	29.3
10	37.9	0.7037	40.5	0.7622	27.5	28.8
20	28.4	0.4972	32.6	0.5880	22.1	24.6
30	21.8	0.3518	26.7	0.4602	17.9	21.1
40	17.1	0.2492	22.4	0.3660	14.6	18.3
50	13.8	0.1767	19.2	0.2964	12.1	16.1
60	11.4	0.1253	16.9	0.2446	10.3	14.4
70	9.8	0.0889	15.1	0.2058	8.9	13.1
80	8.6	0.0631	13.8	0.1765	7.9	12.1
90	7.8	0.0448	12.7	0.1541	7.2	11.3
100	7.2	0.0318	12.0	0.1369	6.7	10.7
110	6.7	0.0226	11.3	0.1233	6.3	10.2
120	6.4	0.0161	10.8	0.1125	6.0	9.8

Figure 5.18 shows a comparison of moisture content (d.b.) versus time for the experimental data and as calculated by the two models – Sharaf and Friant for a randomly selected data set. The Friant equation has the faster drying rate – i.e., has the steepest curve; at 120 hours, the Friant curve is closer to the equilibrium moisture content than is the model developed by Sharaf-Eldeen et al. (1980). Figure 5.19 shows a comparison of the moisture ratio versus time for experimental data and the two models.

Statistically, when comparing the Sharaf model to the validation set, the SEP for the moisture ratio is 0.2000, which is larger than the SEP for the Friant model (0.1147). The SEP for the moisture content was 6.7%, d.b., which is larger than the SEP for the Friant model (3.8%, d.b.). The SEP/SEC ratio for the Sharaf equation cannot be determined, because there are no calibration statistics available to the author. Complete calculation of the SEP for the Sharaf model can be found in Appendix A. The effect of the two models on the deep-bed model will be discussed in Section 5.7.

Another comparison for the Friant and Sharaf models is to compare the SEP values during the first half of drying (MRAT≥0.5) and the SEP values during the second half of drying (MRAT<0.5) (Table 5.6).

Table 5.6 SEP values for the Friant and Sharaf models during the first half of drying (MRAT≥0.5) and the SEP values during the second half of drying (MRAT<0.5).

	Friant		Sharaf	
MRAT	M.C. (%, d.b.)	MRAT	M.C. (%, d.b.)	MRAT
>=0.5	4.2	0.1108	4.3	0.1170
<0.5	3.4	0.1204	9.0	0.2740

Table 5.6 shows that after the moisture ratio decreases below 0.5, the Sharaf model becomes very poor at predicting the moisture ratio and moisture content. When applying the thin-layer model to the deep-bed model, the prediction of moisture content during the last portion of drying is particularly important in predicting the total drying time. Table 5.6 shows that the Sharaf model will not predict as well as the newly parameterized model during the last portion of drying (MRAT < 0.5).

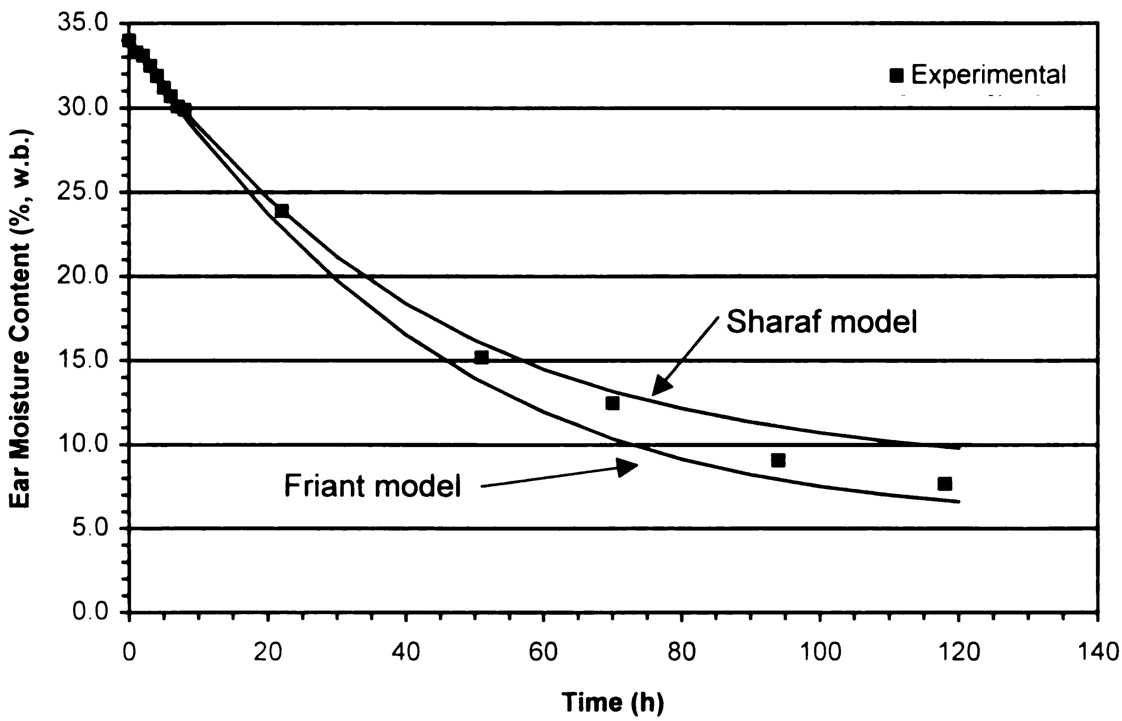

Figure 5.18 Moisture content versus time for the two thin-layer models and the experimental data dried at 40°C (104°F), 7% r.h.

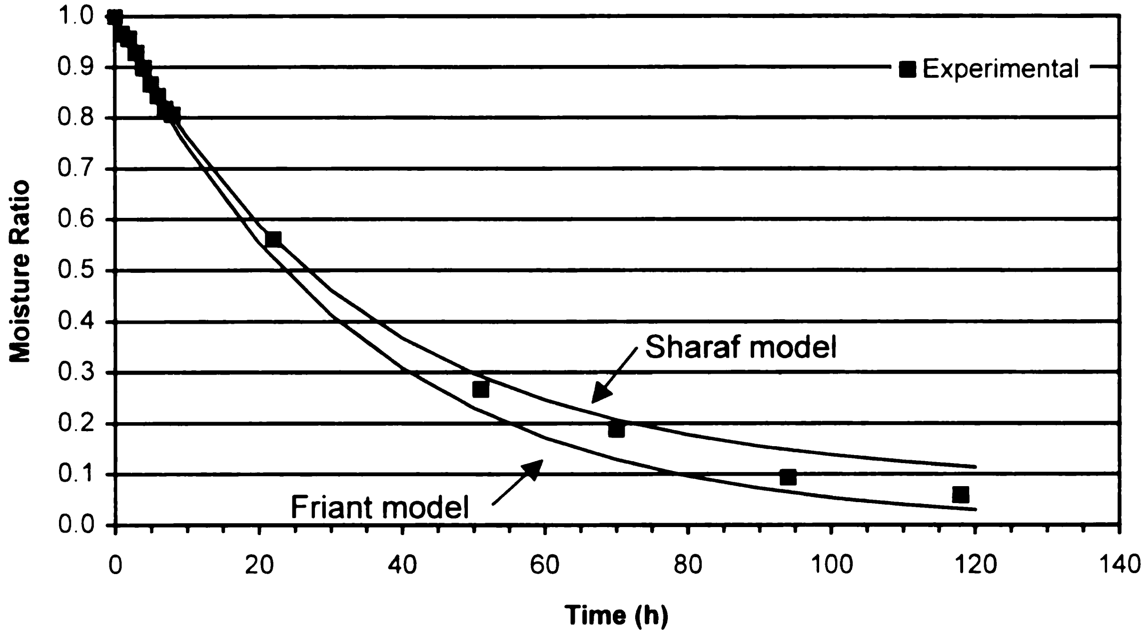

Figure 5.19 Moisture ratio versus time for the two thin-layer models and the experimental data dried at 40°C (104°F), 7% r.h.

A comparison of the time for the Friant and Sharaf models to predict moisture contents of 22% (w.b.) and 12.5% (w.b.) is tabulated in Table 5.7. The drying air temperatures used were 35, 37.8, 40.6, 43.3, and 46.1°C (95, 100, 105, 110, and 115°F); the initial moisture contents used were 35, 30, and 25% (w.b.), and the relative humidity was 15%. For the initial ear moisture contents of 35 and 30% (w.b.), the Friant model calculates shorter times to reach the 12.5% (w.b.) moisture content. The large times for the Sharaf model to reach 12.5% (w.b.) at 35, 37.8, and 40.6°C (95, 100, and 105°F) should be noted.

Table 5.7 Time (h) for the moisture content in the Friant and Sharaf models to predict 22 and 12.5% (w.b.) at different temperatures and initial moisture contents at 15% relative humidity.

Goal M.C. (%, w.b.)	Temp. Deg. C	Initial Ear Moisture Contents (%, w.b.)					
		35		30		25	
		Friant	Sharaf	Friant	Sharaf	Friant	Sharaf
22.0	35.0	34	44	20	19	7	6
12.5	35.0	86	150	63	77	45	41
22.0	37.8	29	40	18	17	7	5
12.5	37.8	72	135	57	70	44	37
22.0	40.6	24	36	16	16	7	5
12.5	40.6	59	120	52	63	42	33
22.0	43.3	20	32	14	14	7	4
12.5	43.3	49	108	46	57	41	30
22.0	46.1	16	29	13	13	6	4
12.5	46.1	40	97	41	51	39	28

5.5 MODEL SENSITIVITY TO VARYING DRYING CONDITIONS

To gain a better understanding of how sensitive the newly parameterized model is to changing conditions, the effects of the drying conditions were examined. As the drying conditions vary – i.e., drying-air temperature, drying-air relative humidity, and initial moisture content – the drying rate of ear corn changes. The new thin-layer model was run using varying inputs to illustrate these relative effects. The standard initial inputs were chosen based on a possible normal range of inputs that may occur in actual drying. The standard initial inputs were:

Drying-air temperature = 40°C (104°F)

Drying-air relative humidity = 20%

Initial ear-corn moisture content = 35.6% (w.b.)

To quantify the effects of the drying-air temperature and relative humidity, the time to reach 10-percentage point moisture content reduction [from 35.6% (w.b.) to 25.6% (w.b.)] was compared for each input condition.

As the drying-air temperature increases, the time for ear corn to reach the 10-percentage point reduction will decrease. Figure 5.20 shows the effect of the drying-air temperature on the time to reach 25.6% (w.b.) for three temperatures: 35, 40, and 45° C. The fastest temperature at which the 10-percentage point reduction is reached is 45°C (13 h); the slowest temperature at which the 10-percentage point reduction is reached is 35°C (26 h).

Figure 5.21 shows the effects of the relative humidity on the time to reach 25.6% (w.b.) for three relative humidities: 15, 20, and 25%. At the lowest humidity (15%) it takes 17 h to reach 25.6% moisture content, while at the highest humidity (25%), it requires 19 h.

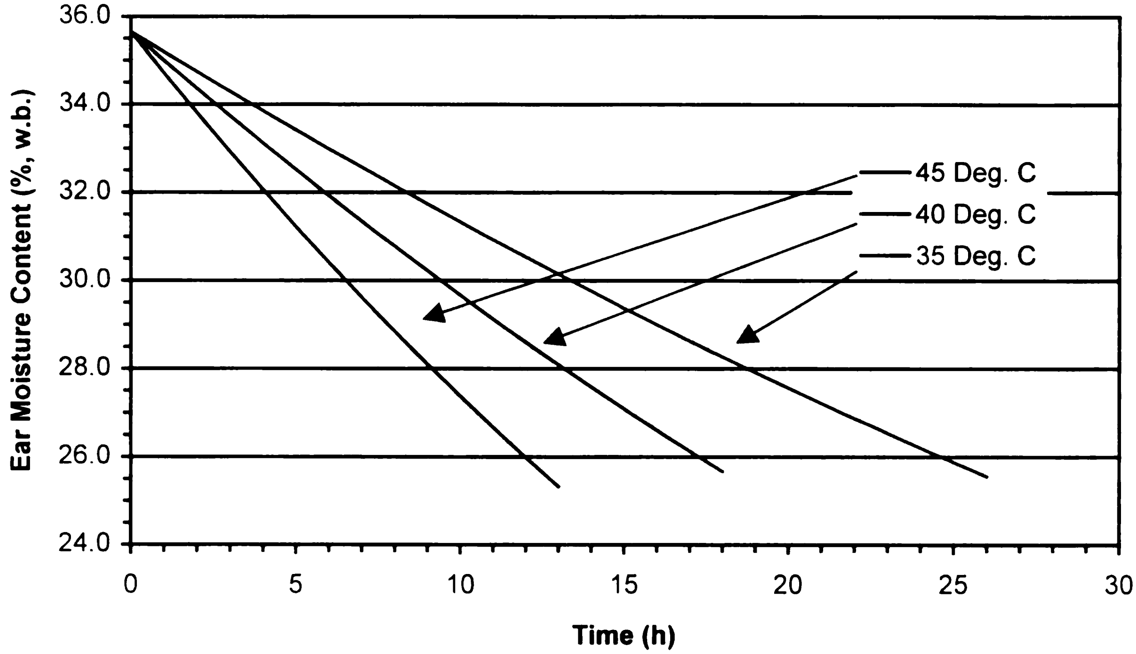

Figure 5.20 Moisture content versus time to reach 25.6% ear moisture content (w.b.) for the new thin-layer model at three temperatures: 35, 40, and 45°C. Initial ear moisture content = 35.6% (w.b.), relative humidity = 20%.

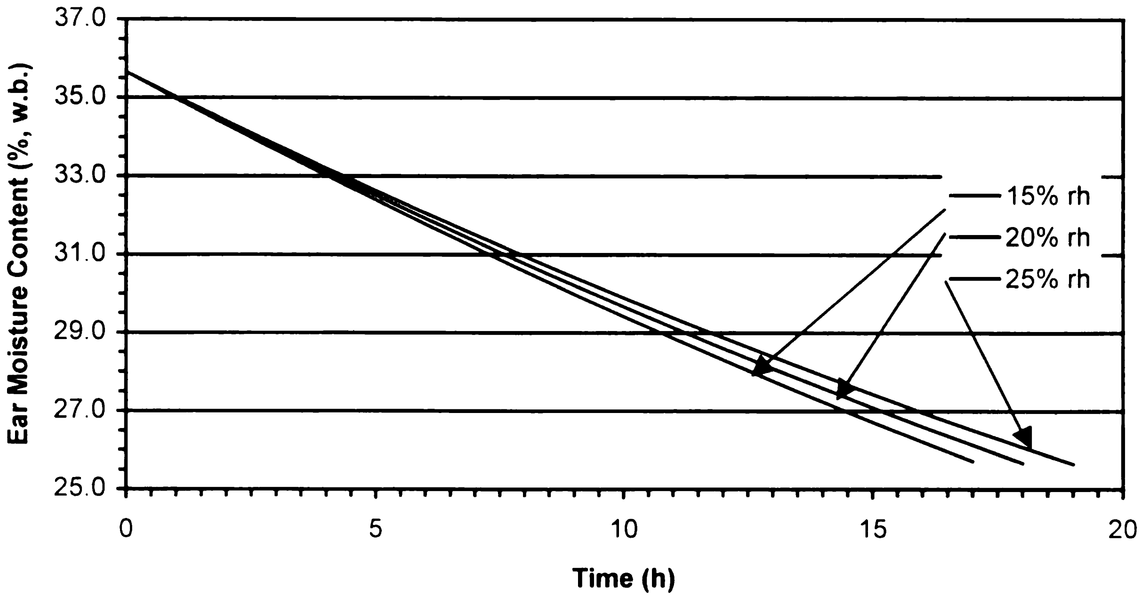

Figure 5.21 Moisture content versus time to reach 25.6% ear moisture content (w.b.) for the new thin-layer model at three relative humidities: 15, 20, and 25%. Initial ear moisture content = 35.6% (w.b.), temperature = 40°C.

To illustrate the sensitivity to initial moisture content for the new thin-layer model, the time for each initial moisture content to reduce 10-percentage points was analyzed. The initial ear moisture contents were 29.4, 35.6, and 41.4% (w.b.). The time for the ear moisture content to reach 19.4, 25.6, and 31.4% (w.b.), for each initial ear moisture content, respectively, was calculated. Figure 5.22 shows the ear moisture content versus the time to reach a 10-percentage point reduction for each of the initial moisture contents.

In Figure 5.22, the initial moisture content of 41.4% (w.b.) requires the shortest time to reach the 10-percentage point reduction; the initial moisture content of 29.4% (w.b.) requires the longest time. This demonstrates that higher initial moisture contents result in a faster drying rates (i.e., it is easier to remove water from a higher moisture content sample than from a lower moisture content sample). This can also be seen in a direct comparison of the three drying rates[3] (see Figure 5.23). The upper curve is for an initial moisture content of 41.4% (w.b.), and the lower curve is the lower initial moisture content of 29.4% (w.b.).

[3] The drying rate here is defined as average percentage points of moisture (w.b.) lost per hour [points/hour]. Drying rate will also be addressed in terms of kg of water per metric tonne of grain per hour.

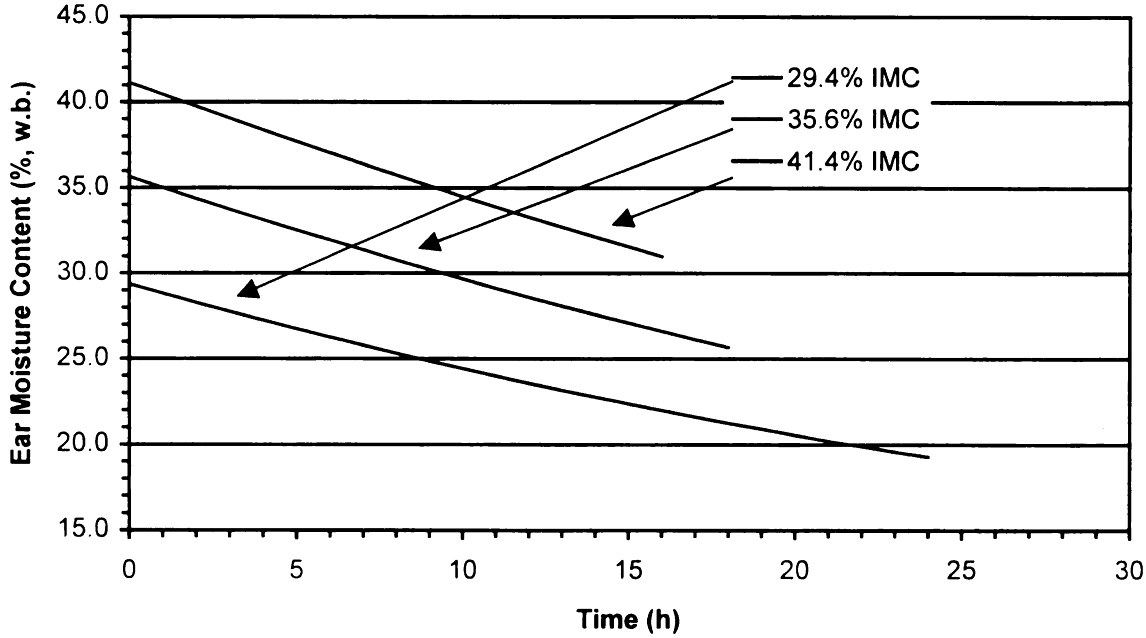

Figure 5.22 Ear moisture content versus time for the new thin-layer model at three initial moisture contents: 29.4, 35.6, and 41.4% (w.b.). Temperature = 40°C, relative humidity = 20%.

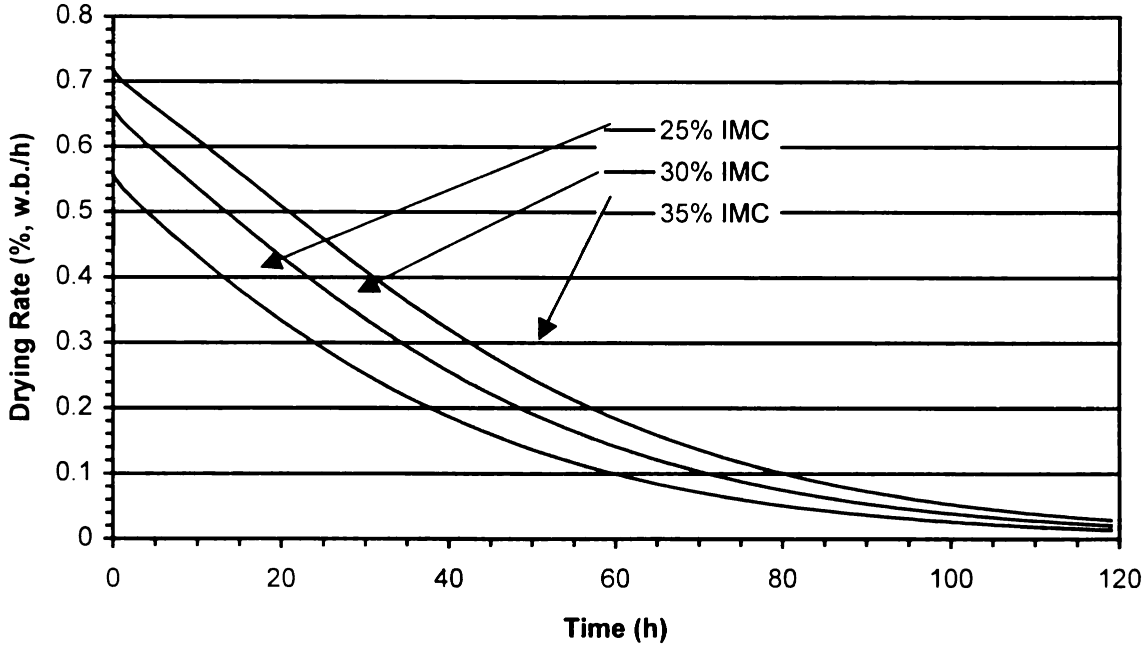

Figure 5.23 Drying rate vs. time for the new thin-layer model at three initial moisture contents: 29.4, 35.6, and 41.4% (w.b.). Temperature = 40°C, relative humidity = 20%.

The average drying rates are as follows:

41.4% (w.b.) initial ear moisture content → 0.26 points/h

35.6% (w.b.) initial ear moisture content → 0.21 points/h

29.4% (w.b.) initial ear moisture content → 0.16 points/h

The drying rate increases as the initial moisture content increases.

The difference between the longest time and the shortest time to reach 10-percentage point moisture reductions across a normal range of drying conditions can determined by inspecting Figures 5.20, 5.21, 5.22. The resulting differences are:

Drying-air temperature (45 to 35°C) → 13 h

Drying-air relative humidity (25 to 15%)→ 2 h

Initial moisture content (35 to 25% [w.b.]) → 8 h

The greatest effect on time to reach a 10-percentage point moisture content reduction results from the changing drying-air temperature.

The average amount of water lost per hour to reach the 10-percentage point moisture content reduction from a one metric tonne (1,000 kg) sample can also be used to evaluate which initial condition has the greatest effect in the new thin-layer model. The units chosen for calculating drying rate for this case are kilograms of water for an initial mass of one tonne (1,000-kilograms) of ear corn per hour (i.e., kg/tonne/h). For ease of calculation, the dry basis moisture content is used to determine the amount of water removed. Table 5.8 shows the average drying rate and the difference between the fastest and slowest average drying rate for each initial condition. The standard initial inputs for Table 5.8 were:

Drying-air temperature = 40°C (104°F)

Drying-air relative humidity = 20%

Initial ear-corn moisture content = 55.3% (d.b.)

The average amount of water removed per hour is more sensitive to the initial moisture content than to the drying-air temperature and relative humidity in the relevant ranges.

Table 5.8 Drying rate (kg/tonne/h) differences for each initial condition to determine which initial condition has the greatest effect on drying rate (kg/tonne/h).

Temperature (Deg. C)	Drying rate (kg/tonne/h)	Largest Drying rate Difference
45	1.954	
40	1.370	0.923
35	1.031	

Initial M.C. (%, d.b.)	Drying rate (kg/tonne/h)	
69.9	0.867	0.983
55.4	1.370	
41.6	1.850	

Relative Humidity (%)	Drying rate (kg/tonne/h)	
25	1.322	0.126
20	1.370	
15	1.447	

Table 5.8 suggests that the initial moisture content has the greatest effect on the predicted water removal rate, while inspection of Figures 5.22, 5.23, and 5.24 suggests that the drying-air temperature has the greatest effect on drying time. These effects suggest that in the modeling of thin-layer drying, accurate

determination of the drying-air temperature and the initial moisture content is important in predicting the drying time of ear corn. The effect of the drying-air relative humidity is relatively small compared to the effects of the drying-air temperature and initial moisture content. This is contrary to deep-bed drying, in which the relative humidity does have a significant effect on the total drying time (Islam, 2002, b).

5.6 HYBRID EFFECTS

To determine if there was a bias caused by hybrid type, analysis of variance (ANOVA, α=0.05) was run on the residuals for the moisture ratio and the moisture content from the independent validation set. The hybrid information for the validation data set was designated with a special letter, to protect confidential genetic information. There were nine hybrids in the validation set, letters A through I. Table 5.9 shows the hybrids, number of sampling points for each hybrid, and the bias between the new thin-layer model and the experimental data for that hybrid.

Table 5.9 Bias of the hybrid effect on the moisture ratio (a) and the moisture content (b) (NS = not significant at α = 0.05).

Hybrid	Number Of Samples	Bias (MRAT)
A	18	-0.05056
B	13	-0.08945
C	16	0.05392
D	11	NS
E	11	NS
F	38	NS
G	12	NS
H	10	NS
I	22	NS
	Average = -0.0287	

(a)

Hybrid	Number Of Samples	Bias (%, d.b.)
A	18	NS
B	13	NS
C	16	2.1143
D	11	NS
E	11	NS
F	38	0.9722
G	12	NS
H	10	NS
I	22	NS
	Average = 1.54	

(b)

When analyzing the bias for the hybrid effect on the moisture ratio prediction, hybrids A, B, and C did have a significant bias. When analyzing the hybrid effects on the moisture content, hybrid C (again) and hybrid F showed a significant bias from the model. While it should be noted that certain hybrids might dry slightly faster/slower than average, the bias resulted in only a relatively small error.

5.7 THIN-LAYER EFFECTS ON THE DEEP-BED MODEL

Use of the new thin-layer model or the Sharaf model in the deep-bed ear-corn drying model also has an effect on the drying times – air reversal and dryer shut-off times – and on the final moisture content gradient (i.e., the difference between the average moisture content at the top and bottom of the deep bed). Air reversal time is the time at which the airflow is switched from up-air to down-air (see Figure 1.1 explanation). Dryer shut-off time is the time at which the ear corn being dried has reached the desired moisture content of 12.5% ±0.5% (w.b.). Table 5.10 shows the drying parameters used to compare the effect of the new thin-layer and Sharaf thin-layer models on the deep-bed ear-corn drying model (Islam, 2002, a). The table shows the air reversal times, dryer shut-off times, and the final moisture content gradient.

Table 5.10 Comparison of the reversal time, dryer shut-off time, and final moisture content gradient for the Friant and Sharaf thin-layer models in the deep-bed ear-corn drying model.

Air Temp Before Reversal (Deg. F)	Air Temp After Reversal (Deg. F)	Bed Depth (ft)	Static Pressure (in H2O)	Reversal M.C. (%, w.b.)	Final M.C. (%, w.b.)
95	105	9	2	22	12.5
		Initial Moisture Contents (%, w.b.)			
Ambient Temp. (Deg. F)	Ambient rh (%)	Test #	M.C.		
		1	35		
		2	30		
65	65	3	25		

		Friant		Sharaf	
Test #	Drying Stage	Time (h)	Final M.C. Gradient (%, w.b.)	Time (h)	Final M.C. Gradient (%, w.b.)
1	Reversal	51	0.2	53	1.2
	Shut-off	93		120	
2	Reversal	30	0.8	27	2.9
	Shut-off	75		69	
3	Reversal	12	1.3	9	4.0
	Shut-off	65		41	

This table shows the marked effect that the thin-layer model can have on the deep-bed ear-corn drying model. In Section 5.4.2, the difference in the SEP for the new thin-layer and Sharaf thin-layer models was shown to be relatively large. Table 5.10 shows that the dryer shut-off time and final moisture content gradient in the deep-bed ear-corn drying model are sensitive to the changes in the thin-layer model. In comparing the deep-bed results using the two different thin-layer models, differences in the predicted drying times were as large as 1.5x, and differences in the moisture content gradient were as large as 2.5x.

CHAPTER 6

CONCLUSIONS

The thin-layer drying of ear corn was investigated in order to parameterize a model that accurately predicts the drying rate of the product. To parameterize the new thin-layer drying model for ear corn, four main steps were taken:

1) Experiments were performed to collect data on thin-layer drying.
2) Psychrometric equations were modified to obtain accurate parameter values in the moisture equilibrium and drying rate equations.
3) A five parameter, single term thin-layer model was parameterized with the experimental data and validated against and independent set of field data.
4) The newly developed thin-layer model was inserted and tested in the MSU deep-bed, ear-corn drying model.

The standard error of calibration (SEC) of the new thin-layer model was 0.08185. Validation of the model against the independent field data showed a standard error of prediction (SEP) for the moisture ratio of 0.1147 (equivalent to 3.8% (d.b.). The ratio of the SEP to SEC gave a value of 1.4, showing the new model to be reasonably robust.

The coefficients of the new thin-layer drying model (Equations [5.2] and [5.3]) for ear corn are:

$A = -28.66$

$B = 7947$

$C = 0.2744$

$D = -86.0032$

$n = 0.9915$

When comparing this model to the previously published Sharaf model (Sharaf-Eldeen et al., 1980) the SEP for the new model was 3.8% (d.b.), while the SEP for the Sharaf model was 6.7% (d.b.). Additionally, when evaluating the first half (MRAT ≥ 0.5) and second half (MRAT < 0.5) of drying separately, the new model had an SEP of 4.2 and 3.4% (d.b.), for each half of drying, respectively, while the Sharaf model had an SEP of 4.3 and 9.0% (d.b.), for each half of drying, respectively. This shows that during the second portion of drying (MRAT < 0.5) the new model predicts the moisture content much more accurately than the Sharaf model.

When comparing the effects of the new model and the previously published model of Sharaf-Eldeen (1980) on the deep-bed ear-corn drying model, a relatively large difference in the SEP resulted in relatively large effects on the deep-bed model. This suggests that the deep-bed ear-corn drying model is very sensitive to the thin-layer model.

An illustration of the sensitivity of the new thin-layer model to initial conditions showed that both the drying-air temperature and initial moisture content of the ear corn have a marked effect on the drying times and rates. Conversely, in the deep-bed model, the relative humidity has a significant effect (Islam, 2002, b).

CHAPTER 7

RECOMMENDATIONS FOR FUTURE STUDY

The recommendations for future study are:

1) Test the new thin-layer model with larger temperature, initial moisture content, and relative humidity ranges.
2) Validate the deep-bed model to see “big picture” impact of the new thin-layer model.

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APPENDICES

APPENDIX A

Experimental Data and Validation Tables

Data Tables for MSU Postharvest Laboratory thin-layer data

Data sets 1-21: Dried at 40 Deg. C, 24.3% rh

	1		2		3	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	31.3	1.0000	26.8	1.0000	28.7	1.0000
1	31.1	0.9835	26.4	0.9725	28.6	0.9924
2	30.7	0.9615	26.0	0.9451	28.3	0.9723
3	30.3	0.9368	25.5	0.9066	28.0	0.9471
4	29.8	0.9038	25.0	0.8682	27.5	0.9168
5	29.4	0.8818	24.4	0.8297	27.1	0.8916
7	28.6	0.8350	23.8	0.7858	26.6	0.8563
8	28.3	0.8185	23.3	0.7528	26.2	0.8337
22	23.7	0.5683	18.7	0.4507	22.3	0.5892
25	22.8	0.5216	17.9	0.4013	21.4	0.5413
45	16.9	0.2494	12.6	0.1047	15.9	0.2464
53	14.3	0.1422	11.3	0.0333	14.1	0.1582
72	11.4	0.0295	8.8	-0.0931	10.4	-0.0082
94	9.0	-0.0613	7.4	-0.1590	8.3	-0.1014

	4		5		6	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	31.6	1.0000	27.8	1.0000	26.4	1.0000
1	31.4	0.9874	27.6	0.9852	26.2	0.9888
2	31.1	0.9655	27.3	0.9615	25.9	0.9664
3	30.7	0.9404	26.9	0.9348	25.6	0.9440
4	30.1	0.9090	26.4	0.9022	25.2	0.9104
5	29.8	0.8870	26.0	0.8725	24.8	0.8805
7	29.1	0.8462	25.4	0.8340	24.1	0.8319
8	28.7	0.8274	25.1	0.8132	23.8	0.8095
22	24.4	0.5921	21.1	0.5554	19.8	0.5331
25	23.5	0.5481	20.3	0.5109	19.1	0.4883
45	17.5	0.2689	15.5	0.2411	14.4	0.2044
53	15.6	0.1904	14.0	0.1641	12.9	0.1222
72	11.5	0.0335	10.6	-0.0019	10.0	-0.0347
94	9.1	-0.0543	8.5	-0.0998	8.3	-0.1206

	7		8		9	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	27.6	1.0000	25.0	1.0000	25.3	1.0000
1	27.5	0.9907	24.7	0.9804	25.1	0.9795
2	27.3	0.9721	24.4	0.9489	24.8	0.9557
3	26.9	0.9473	23.9	0.9136	24.4	0.9250
4	26.5	0.9164	23.5	0.8782	23.9	0.8909
5	26.0	0.8854	23.0	0.8428	23.6	0.8602
7	25.4	0.8420	22.4	0.7957	23.0	0.8159
8	25.1	0.8204	22.2	0.7760	22.7	0.7920
22	21.1	0.5664	18.4	0.4971	18.9	0.5192
25	20.4	0.5199	17.7	0.4460	18.2	0.4714
45	15.6	0.2505	13.1	0.1513	13.8	0.1850
53	13.9	0.1637	11.9	0.0767	12.4	0.1032
72	10.5	-0.0066	9.4	-0.0687	9.7	-0.0503
94	8.0	-0.1212	7.9	-0.1552	8.1	-0.1389

	10		11		12	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	24.3	1.0000	28.3	1.0000	26.8	1.0000
1	24.1	0.9786	28.2	0.9878	26.4	0.9751
2	23.7	0.9486	27.8	0.9603	25.8	0.9252
3	23.4	0.9186	27.4	0.9327	25.6	0.9128
4	22.9	0.8801	26.9	0.8991	25.1	0.8754
5	22.5	0.8459	26.5	0.8747	24.6	0.8422
7	21.9	0.7988	25.9	0.8349	24.0	0.7965
8	21.7	0.7816	25.6	0.8135	23.6	0.7674
22	18.0	0.4990	21.4	0.5567	18.9	0.4641
25	17.3	0.4477	20.6	0.5109	18.0	0.4101
45	13.1	0.1565	15.7	0.2418	12.8	0.1111
53	11.8	0.0752	14.0	0.1593	11.3	0.0363
72	9.4	-0.0747	10.8	0.0064	8.9	-0.0883
94	8.0	-0.1603	8.4	-0.0975	7.4	-0.1589

	13		14		15	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	29.3	1.0000	34.0	1.0000	28.7	1.0000
1	29.0	0.9834	33.7	0.9871	28.3	0.9770
2	28.6	0.9570	33.4	0.9661	27.8	0.9397
3	28.2	0.9272	32.9	0.9418	27.2	0.9024
4	27.6	0.8907	32.4	0.9127	26.6	0.8622
5	27.1	0.8609	32.0	0.8901	26.1	0.8249
7	26.4	0.8146	31.3	0.8529	25.3	0.7790
8	26.0	0.7914	31.0	0.8335	24.9	0.7532
22	21.0	0.5000	26.1	0.5944	19.9	0.4604
25	20.2	0.4537	25.2	0.5523	19.1	0.4116
45	14.7	0.1822	18.9	0.2873	13.8	0.1446
53	13.1	0.1060	16.9	0.2146	12.2	0.0700
72	17.4	0.3113	12.7	0.0675	9.2	-0.0620
94	15.8	0.2352	9.5	-0.0359	7.5	-0.1338

	16		17		18	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	31.7	1.0000	32.6	1.0000	28.3	1.0000
1	30.9	0.9500	32.3	0.9790	28.0	0.9748
2	30.7	0.9351	31.8	0.9496	27.5	0.9433
3	30.0	0.8976	31.3	0.9223	27.0	0.9086
4	29.4	0.8576	30.7	0.8886	26.5	0.8739
5	28.8	0.8251	30.2	0.8613	26.0	0.8393
7	28.0	0.7802	29.6	0.8235	25.3	0.7951
8	27.5	0.7527	29.2	0.8046	24.9	0.7668
22	21.7	0.4579	24.5	0.5630	20.0	0.4768
25	20.6	0.4080	23.6	0.5188	19.1	0.4264
45	14.4	0.1432	17.4	0.2520	13.8	0.1490
53	12.6	0.0732	15.5	0.1764	12.2	0.0702
72	9.5	-0.0417	11.4	0.0251	9.2	-0.0653
94	7.7	-0.1041	8.4	-0.0737	7.3	-0.1441

	19		20		21	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	25.8	1.0000	31.5	1.0000	30.5	1.0000
1	25.4	0.9674	31.0	0.9714	30.1	0.9721
2	24.9	0.9282	30.5	0.9381	29.5	0.9380
3	24.4	0.8890	29.9	0.9024	28.9	0.9009
4	23.8	0.8466	29.3	0.8667	28.3	0.8637
5	23.2	0.8042	28.7	0.8334	27.7	0.8265
7	22.6	0.7585	28.0	0.7906	26.9	0.7801
8	22.2	0.7259	27.6	0.7691	26.4	0.7522
22	17.4	0.4028	22.3	0.4930	21.2	0.4672
25	16.5	0.3440	21.3	0.4431	20.2	0.4176
45	11.5	0.0471	15.3	0.1813	14.6	0.1605
53	10.1	-0.0280	13.5	0.1099	12.9	0.0923
72	8.0	-0.1422	10.1	-0.0187	9.6	-0.0409
94	6.7	-0.2075	8.0	-0.0925	7.4	-0.1214

Data sets 22-28: Dried at 40 Deg. C, 7% rh

	22		23		24		25	
Time (h)	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio
0	27.7	1.0000	27.0	1.0000	25.5	1.0000	26.6	1.0000
1	27.4	0.9803	26.5	0.9683	25.0	0.9728	26.1	0.9704
2	26.9	0.9541	25.9	0.9321	24.5	0.9417	25.4	0.9310
3	26.5	0.9278	25.5	0.9094	24.0	0.9107	24.8	0.8966
4	25.9	0.8983	24.9	0.8778	23.5	0.8796	24.3	0.8670
5	25.6	0.8786	24.4	0.8461	22.9	0.8446	23.8	0.8375
6	24.8	0.8359	24.0	0.8234	22.5	0.8213	23.3	0.8079
7	24.6	0.8228	23.5	0.7963	22.0	0.7941	22.8	0.7833
8	24.2	0.8031	23.1	0.7782	21.4	0.7591	22.4	0.7587
22	19.1	0.5472	17.9	0.5156	16.4	0.4911	17.2	0.4927
51	11.6	0.2256	10.7	0.1986	10.3	0.2036	10.2	0.1873
70	9.5	0.1469	9.3	0.1443	9.2	0.1570	8.8	0.1282
94	7.9	0.0878	7.9	0.0900	7.7	0.0948	7.4	0.0741
118	6.9	0.0517	7.0	0.0583	7.0	0.0638	6.6	0.0445
140	5.8	0.0156	5.9	0.0175	6.5	0.0443	5.9	0.0199
162	5.7	0.0091	5.8	0.0130	5.8	0.0172	5.5	0.0051
Final	0.0		0.0		0.0		0.0	

	26		27		28		
Time (h)	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	Time (h)	M.C. (%, w.b.)	Moisture Ratio
0	34.0	1.0000	37.7	1.0000	0	24.8	1
1	33.3	0.9653	37.4	0.9839	2.5	23.2	0.893916
2	33.1	0.9560	36.7	0.9553	22	16.2	0.494335
3	32.5	0.9283	36.1	0.9285	27	14.6	0.416541
4	31.9	0.8982	35.5	0.9000	46	10.4	0.211446
5	31.2	0.8658	34.9	0.8732	73	8.1	0.108898
6	30.7	0.8427	34.4	0.8517	94	7.4	0.080609
7	30.1	0.8172	33.9	0.8321	99	7.2	0.073537
8	29.9	0.8057	33.6	0.8178	117.5	6.5	0.041712
22	23.9	0.5604	27.6	0.5909	123	6.4	0.038176
51	15.2	0.2666	17.6	0.2855	141	6.0	0.020495
70	12.5	0.1880	14.6	0.2087	147.5	5.9	0.016959
94	9.1	0.0931	8.9	0.0747			
118	7.7	0.0584	7.5	0.0443			
140	6.7	0.0330	6.5	0.0229			
162	6.1	0.0168	6.1	0.0139			
Final	0.0		0.0				

Data sets 29-37: Dried at 35 Deg. C, 11.4% rh

	29		30		31		32	
Time (h)	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio
0	27.8	1.0000	27.8	1.0000	28.0	1.0000	24.1	1.0000
1	27.0	0.9498	27.0	0.9536	27.1	0.9412	23.4	0.9464
2	26.3	0.9087	26.4	0.9179	26.4	0.8993	22.8	0.9062
3	25.6	0.8677	25.8	0.8821	25.7	0.8615	22.2	0.8659
4	25.1	0.8357	25.4	0.8571	25.1	0.8279	21.8	0.8347
5	24.5	0.8038	24.8	0.8250	24.5	0.7943	21.2	0.7989
6	23.9	0.7718	24.4	0.8000	24.1	0.7691	20.9	0.7766
7	23.4	0.7399	24.0	0.7750	23.5	0.7398	20.5	0.7497
24.5	15.5	0.3474	17.0	0.4178	15.9	0.3620	14.4	0.3788
27.5	14.6	0.3063	16.2	0.3821	15.0	0.3200	13.6	0.3386
32	13.2	0.2470	14.9	0.3214	13.5	0.2571	12.6	0.2805
48	9.9	0.1101	11.4	0.1714	10.4	0.1269	10.0	0.1465
53	9.2	0.0827	10.6	0.1393	9.7	0.1017	9.6	0.1241
55.3	8.9	0.0690	10.3	0.1250	9.4	0.0892	9.3	0.1107
72	7.7	0.0233	8.9	0.0714	8.2	0.0430	8.2	0.0571
76.5	7.4	0.0142	8.7	0.0607	8.0	0.0346	8.0	0.0437
79.5	7.2	0.0051	8.6	0.0571	7.9	0.0304	7.8	0.0347
97.5	6.6	-0.0177	7.8	0.0285	7.2	0.0052	7.1	0.0035
103	6.3	-0.0269	7.6	0.0214	7.1	0.0010	6.9	-0.0055
Final	0.0		0.0		0.0		0.0	

	33		34		35		36	
Time (h)	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio
0	28.0	1.0000	27.1	1.0000	27.8	1.0000	25.5	1.0000
1	27.2	0.9515	26.3	0.9491	27.1	0.9540	24.7	0.9484
2	26.6	0.9175	25.8	0.9151	26.5	0.9195	24.2	0.9122
3	26.1	0.8835	25.1	0.8769	25.9	0.8812	23.6	0.8761
4	25.6	0.8544	24.6	0.8472	25.4	0.8544	23.1	0.8451
5	25.1	0.8252	24.1	0.8175	24.9	0.8238	22.6	0.8141
6	24.6	0.8010	23.7	0.7920	24.4	0.7969	22.2	0.7883
7	24.2	0.7767	23.3	0.7665	23.9	0.7701	21.8	0.7625
24.5	17.3	0.4272	16.4	0.4057	16.9	0.4100	15.7	0.4165
27.5	16.4	0.3835	15.6	0.3675	16.0	0.3678	15.0	0.3752
32	15.2	0.3301	14.3	0.3081	14.6	0.3065	13.8	0.3184
48	11.7	0.1796	10.9	0.1553	10.9	0.1495	11.0	0.1790
53	11.0	0.1505	10.3	0.1298	10.1	0.1188	10.5	0.1532
55.3	10.6	0.1359	9.9	0.1128	9.9	0.1073	10.1	0.1377
72	9.1	0.0776	8.5	0.0576	8.4	0.0498	9.0	0.0861
76.5	8.9	0.0679	8.3	0.0492	8.2	0.0422	8.8	0.0758
79.5	8.7	0.0631	8.1	0.0402	8.0	0.0345	8.7	0.0706
97.5	7.8	0.0291	7.3	0.0110	7.2	0.0039	8.0	0.0396
103	7.7	0.0242	7.1	0.0025	7.1	0.0000	7.8	0.0344
Final	0.0		0.0		0.0		0.0	

	37	
Time (h)	M.C. (%, w.b.)	Moisture Ratio
0	24.3	1.0000
1	23.6	0.9467
2	23.0	0.9111
3	22.5	0.8755
4	22.0	0.8400
5	21.6	0.8103
6	21.2	0.7860
7	20.7	0.7570
24.5	14.7	0.3954
27.5	14.1	0.3599
32	13.0	0.3006
48	10.4	0.1643
53	9.8	0.1346
55.3	9.6	0.1228
72	8.4	0.0635
76.5	8.3	0.0576
79.5	8.0	0.0457
97.5	7.4	0.0161
103	7.2	0.0042
Final	0.0	

Data Sets 38-46: Dried at 45 Deg. C, 6.98% rh

	38		39		40		41	
Time (h)	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio
0	27.2	1.0000	23.5	1.0000	25.8	1.0000	25.9	1.0000
1	26.3	0.9491	22.3	0.9208	24.9	0.9402	25.0	0.9435
2	25.4	0.8983	21.3	0.8528	23.8	0.8761	24.1	0.8905
3	24.4	0.8378	20.0	0.7736	22.6	0.8078	23.1	0.8304
4	23.4	0.7870	18.9	0.7057	21.6	0.7523	22.2	0.7810
5	22.8	0.7520	18.3	0.6661	20.9	0.7139	21.6	0.7456
6	22.1	0.7170	17.5	0.6208	20.1	0.6711	20.8	0.7033
7	21.5	0.6852	16.9	0.5868	19.6	0.6412	20.3	0.6750
24.5	13.5	0.3164	9.9	0.2133	11.6	0.2569	12.8	0.3076
47.5	8.2	0.1065	7.3	0.0888	7.4	0.0818	8.1	0.1098
50	7.8	0.0906	7.0	0.0775	7.2	0.0732	7.8	0.0956
72.5	6.2	0.0302	6.1	0.0379	6.0	0.0262	6.3	0.0391
78.5	6.0	0.0239	5.9	0.0265	5.8	0.0177	6.1	0.0320
96	5.4	0.0048	5.5	0.0096	5.3	0.0006	5.6	0.0109
98.5	5.3	0.0016	5.4	0.0039	5.3	0.0006	5.6	0.0109
104	5.3	-0.0016	5.3	-0.0018	5.2	-0.0037	5.4	0.0038
126.5	4.8	-0.0175	5.3	-0.0018	4.8	-0.0207	5.0	-0.0103
150	4.5	-0.0270	4.9	-0.0187	4.5	-0.0293	4.7	-0.0245
168	4.3	-0.0366	4.9	-0.0187	4.3	-0.0378	4.5	-0.0315
Final	0.0		0.0		0.0		0.0	

	42		43		44		45	
Time (h)	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio	M.C. (%, w.b.)	Moisture Ratio
0	27.4	1.0000	26.4	1.0000	25.5	1.0000	26.5	1.0000
1	26.6	0.9551	25.5	0.9457	24.7	0.9484	25.7	0.9516
2	25.8	0.9069	24.6	0.8915	23.9	0.9007	24.9	0.9069
3	24.7	0.8492	23.5	0.8281	22.9	0.8412	23.9	0.8474
4	23.9	0.8043	22.5	0.7739	22.0	0.7895	23.0	0.7990
5	23.3	0.7722	21.8	0.7332	21.5	0.7578	22.4	0.7617
6	22.6	0.7369	20.9	0.6880	20.8	0.7181	21.7	0.7245
7	22.1	0.7080	20.3	0.6563	20.3	0.6903	21.2	0.6984
24.5	14.4	0.3518	11.7	0.2538	13.0	0.3249	13.4	0.3262
47.5	9.1	0.1368	7.6	0.0865	8.3	0.1185	8.7	0.1288
50	8.7	0.1207	7.4	0.0774	7.9	0.1026	8.4	0.1177
72.5	7.0	0.0598	6.2	0.0322	6.3	0.0390	7.0	0.0618
78.5	6.7	0.0501	5.9	0.0232	6.1	0.0311	6.7	0.0507
96	6.2	0.0309	5.4	0.0051	5.6	0.0112	6.2	0.0320
98.5	6.1	0.0277	5.4	0.0051	5.5	0.0073	6.2	0.0320
104	6.0	0.0245	5.3	0.0005	5.4	0.0033	6.0	0.0246
126.5	5.5	0.0084	4.9	-0.0135	5.0	-0.0126	5.6	0.0097
150	5.2	-0.0044	4.6	-0.0266	4.7	-0.0245	5.4	0.0023
168	5.0	-0.0108	4.5	-0.0311	4.4	-0.0364	5.1	-0.0089
Final	0.0		0.0		0.0		0.0	

	46	
Time (h)	M.C. (%, w.b.)	Moisture Ratio
0	27.2	1.0000
1	26.3	0.9498
2	25.4	0.8960
3	24.3	0.8385
4	23.4	0.7883
5	22.8	0.7560
6	22.1	0.7198
7	21.6	0.6914
24.5	13.5	0.3147
47.5	8.4	0.1138
50	8.0	0.0995
72.5	6.5	0.0420
78.5	6.2	0.0313
96	5.7	0.0133
98.5	5.7	0.0133
104	5.5	0.0062
126.5	5.1	-0.0082
150	4.8	-0.0189
168	4.6	-0.0261
Final	0.0	

Data sets 47-65: Dried at 40 Deg. C, 12.1% rh

	47		48		49		50	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	23.9	1.0000	25.2	1.0000	22.2	1.0000	24.8	1.0000
1	22.8	0.9209	24.7	0.9709	21.6	0.9485	24.3	0.9679
2	23.3	0.9548	24.2	0.9345	20.7	0.8840	23.7	0.9295
3	22.8	0.9209	23.5	0.8908	20.2	0.8454	23.4	0.9038
4	22.1	0.8757	23.0	0.8543	19.5	0.7938	22.9	0.8718
5	21.5	0.8304	22.5	0.8252	18.8	0.7423	22.2	0.8269
6	21.0	0.7965	21.7	0.7742	18.4	0.7165	21.9	0.8077
7	20.6	0.7739	21.3	0.7524	16.5	0.5877	21.4	0.7756
8	20.1	0.7400	21.1	0.7378	16.3	0.5748	21.0	0.7500

	51		52		53		54	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	25.9	1.0000	25.0	1.0000	27.4	1.0000	28.2	1.0000
1	25.7	0.9847	24.7	0.9791	26.9	0.9646	27.9	0.9819
2	25.2	0.9541	24.2	0.9457	26.2	0.9222	27.4	0.9528
3	24.8	0.9234	23.7	0.9122	25.4	0.8798	26.7	0.9093
4	24.4	0.8979	23.2	0.8830	24.8	0.8444	26.3	0.8911
5	23.8	0.8622	22.8	0.8537	24.2	0.8091	25.8	0.8585
6	23.5	0.8417	22.4	0.8287	23.7	0.7808	25.3	0.8331
7	23.0	0.8111	22.0	0.8036	23.2	0.7525	24.9	0.8113
8	22.6	0.7907	21.6	0.7785	22.8	0.7313	24.5	0.7895

	55		56		57		58	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	29.3	1.0000	24.4	1.0000	30.1	1.0000	29.3	1.0000
1	28.9	0.9792	24.0	0.9742	30.0	0.9898	28.9	0.9807
2	28.4	0.9515	23.6	0.9433	29.4	0.9590	28.4	0.9498
3	27.9	0.9238	23.1	0.9072	28.9	0.9317	27.6	0.9073
4	27.4	0.8926	22.6	0.8762	28.4	0.9044	27.3	0.8880
5	26.8	0.8614	22.1	0.8401	27.9	0.8771	26.7	0.8533
6	26.4	0.8372	21.6	0.8092	27.5	0.8532	25.9	0.8108
7	25.9	0.8129	21.2	0.7834	27.0	0.8293	25.7	0.8031
8	25.5	0.7887	20.9	0.7627	26.6	0.8088	25.2	0.7760

	59		60		61		62	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	29.7	1.0000	30.5	1.0000	23.8	1.0000	24.7	1.0000
1	29.2	0.9703	29.9	0.9673	22.8	0.9319	24.2	0.9625
2	28.4	0.9259	29.2	0.9313	21.8	0.8637	23.4	0.9099
3	27.7	0.8873	28.5	0.8920	20.9	0.8041	22.6	0.8574
4	27.0	0.8487	28.0	0.8625	20.4	0.7700	21.9	0.8124
5	26.5	0.8221	27.3	0.8265	19.5	0.7104	21.2	0.7673
6	25.9	0.7924	26.8	0.8003	18.8	0.6678	20.8	0.7448
7	25.2	0.7568	26.2	0.7708	18.2	0.6252	20.2	0.7073
8	24.9	0.7390	25.7	0.7479	17.6	0.5912	19.8	0.6847

	63		64		65	
Time (h)	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT	M.C. (%, w.b.)	MRAT
0	26.2	1.0000	24.9	1.0000	24.5	1.0000
1	25.7	0.9667	24.5	0.9734	24.1	0.9677
2	24.8	0.9085	23.8	0.9309	23.4	0.9246
3	23.8	0.8502	23.1	0.8831	22.8	0.8815
4	21.4	0.7088	22.6	0.8512	22.3	0.8492
5	22.2	0.7504	21.9	0.8034	21.6	0.8062
6	21.6	0.7171	21.5	0.7769	21.2	0.7792
7	21.0	0.6838	21.0	0.7503	20.7	0.7469
8	20.4	0.6505	20.6	0.7237	20.3	0.7200

Data table for drying conditions of the bottom- and top-layer field data.
Initial moisture content has been converted from kernel to ear moisture content.

Bin	Fill					IMC	IMC	Upair			Downair		
#	#	Code	Code	Code	Code	(%, w.b.)	(%, d.b.)	Deg. F	R.H.	EMC (%, d.b.)	Deg. F	R.H.	EMC (%, d.b.)
307	1	66	89	90	91	34.8	53.4	97.7	28.39	13.3	110.1	28.15	13.0
307	2	67	92	93	94	32.7	48.6	100.2	34.89	15.2	108.0	19.04	10.2
307	3	68	95	96	97	37.5	60.0	98.7	21.29	11.0	106.4	16.17	9.3
307	4	69	98	99	100	35.4	54.8	97.5	32.08	14.4	106.8	21.92	11.2
307	5	70	101	102	103	36.2	56.9	97.3	30.46	13.9	105.7	13.70	8.1
307	6	71	104	105	106	34.4	52.5	98.3	20.27	10.7	101.6	18.68	10.2
307	11	72	107	108	109	40.9	69.3	98.5	14.39	8.7	102.2	13.20	8.2
317	1	73	110	111	112	35.3	54.5	98.1	27.81	13.1	110.0	28.27	13.1
317	2	74	113	114	115	33.6	50.6	99.5	34.72	15.2	108.4	19.59	10.4
317	3	75	116	117	118	41.9	72.2	99.0	21.31	11.1	105.9	16.96	9.5
317	4	76	119	120	121	35.7	55.4	98.8	31.14	14.1	106.3	21.12	10.9
317	5	77	122	123	124	33.7	50.8	97.9	29.97	13.8	106.4	13.86	8.5
317	6	78	125	126	127	39.4	65.0	98.0	22.36	11.4	104.9	16.00	9.2
317	7	79	128	129	130	39.4	65.0	97.6	24.45	12.1	106.6	18.03	9.9
317	11	80	131	132	133	40.4	67.9	97.8	19.73	10.6	102.9	11.62	7.6
319	1	81	134	135	136	37.7	60.6	97.2	29.12	13.5	110.0	28.44	13.1
319	2	82	137	138	139	32.5	48.1	99.9	37.99	11.1	107.3	19.75	10.5
319	3	83	140	141	142	39.0	63.8	96.1	24.46	12.1	106.3	15.79	9.1
319	4	84	143	144	145	37.7	60.6	97.7	29.43	13.6	106.8	22.43	11.3
319	5	85	146	147	148	38.0	61.2	97.8	30.76	14.0	106.3	18.98	10.2
319	6	86	149	150	151	36.1	56.6	99.1	20.99	10.9	101.0	19.52	10.4
319	7	87	152	153	154	37.1	58.9	97.5	24.79	12.2	104.4	19.97	10.6
319	11	88	155	156	157	39.6	65.6	98.6	14.65	8.8	102.8	12.98	8.2

Data tables for field data collected at Pioneer Hi-Bred International, Constantine, Michigan

Bottom-layer field data: data sets 66-88
Code numbers are printed in bold in upper left-hand corner of each data set.

Bin 307 Fill #1				
66	EMC (%,d.b.)= 13.3			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	34.8	53.4	1.0000	94.8
14.2	30.3	43.4	0.7515	98.9
22.2	28.5	39.8	0.6600	99.6
30.2	26.2	35.5	0.5536	98.0
38.2	24.1	31.7	0.4584	97.7
46.2	22.9	29.6	0.4069	94.9
54.2	16.3	19.5	0.1550	95.0

Bin 307, Fill #2				
67	EMC (%,d.b.)= 15.2			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	32.7	48.6	1.0000	102.7
6.8	30.5	44.0	0.8611	101.5
14.8	25.7	34.5	0.5785	103.8
22.8	21.9	28.1	0.3849	99.0
30.8	19.0	23.4	0.2457	95.7
38.8	15.7	18.6	0.1015	97.3
46.8	12.6	14.4	-0.0232	101.0

Bin 307, Fill #3				
68	EMC (%,d.b.)= 11.0			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	37.5	60.0	1.0000	93.9
2.42	40.8	69.1	1.1837	98.5
10.42	37.6	60.3	1.0059	100.3
18.42	36.2	56.9	0.9348	99.3
34.42	31.7	46.4	0.7218	99.0

Bin 307, Fill #4				
69	EMC (%,d.b.)= 14.4			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	35.4	54.8	1.0000	92.0
11	30.3	43.4	0.7181	96.6
19	29.4	41.6	0.6723	98.7
27	21.2	27.0	0.3109	95.6
35	23.8	31.2	0.4159	98.1

Bin 307, Fill #5				
70	EMC (%,d.b.)= 13.9			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	36.2	56.9	1.0000	91.0
4.5	33.7	50.8	0.8602	99.5
12.5	31.2	45.3	0.7314	99.4
20.5	27.1	37.2	0.5432	93.5
28.5	24.7	32.9	0.4412	95.0
36.5	23.8	31.2	0.4032	99.4
44.5	15.3	18.0	0.0966	98.6

Bin 307, Fill #6				
71	EMC (%,d.b.)= 10.7			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	34.4	52.5	1.0000	86.3
9.08	29.5	41.8	0.7443	99.1
25.08	24.3	32.1	0.5125	98.7
33.08	21.0	26.5	0.3785	98.9
41.08	17.1	20.7	0.2378	99.0

Bin 307, Fill #11				
72	EMC (%,d.b.)= 8.7			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	40.9	69.3	1.0000	84.4
18.08	31.4	45.9	0.6127	101.4
26.08	28.1	39.0	0.4996	99.3
34.08	28.6	40.0	0.5165	99.3

Bin 317, Fill #1				
73	EMC (%,d.b.)= 13.1			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	35.3	54.5	1.0000	97.9
6.75	33.6	50.6	0.9040	99.8
22.75	30.8	44.5	0.7578	100.3
30.75	23.8	31.2	0.4371	99.6
38.75	21.4	27.2	0.3398	97.9
46.75	18.8	23.2	0.2439	94.0

Bin 317, Fill #2				
74	EMC (%,d.b.)= 15.2			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	33.6	50.6	1.0000	99.5
21.7	27.4	37.7	0.6371	100.0
29.7	26.7	36.5	0.6019	99.0
37.7	24.1	31.7	0.4660	94.0
45.7	18.0	22.0	0.1926	99.0
61.7	16.5	19.7	0.1273	97.1

Bin 317, Fill #3				
75	EMC (%,d.b.)= 11.1			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	41.9	72.2	1.0000	94.1
4	38.5	62.7	0.8444	99.8
12	34.7	53.1	0.6879	98.0
20	30.8	44.5	0.5470	102.6
36	21.8	27.8	0.2741	99.7
44	18.8	23.2	0.1982	100.2

Bin 317, Fill #4				
76	EMC (%,d.b.)= 14.1			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	35.7	55.4	1.0000	98.8
8.83	27.8	38.5	0.5904	100.1
16.83	28.1	39.0	0.6028	100.2
24.83	25.7	34.5	0.4945	101.9
32.83	23.4	30.5	0.3977	98.8
40.83	23.8	31.2	0.4144	95.0

Bin 317, Fill #5				
77	EMC (%,d.b.)= 13.8			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	33.7	50.8	1.0000	94.0
11	30.9	44.8	0.8361	97.7
19	23.5	30.8	0.4577	98.0
27	23.0	29.8	0.4331	98.0
35	17.2	20.8	0.1901	97.0

Bin 317, Fill #6				
78	EMC (%,d.b.)= 11.4			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	39.4	65.0	1.0000	97.5
11.67	33.0	49.2	0.7045	101.6
19.67	29.9	42.6	0.5827	97.8
27.67	28.5	39.8	0.5292	100.2
35.67	24.2	31.9	0.3826	100.0
43.67	20.8	26.3	0.2784	97.5
51.76	19.5	24.2	0.2393	92.6

Bin 317, Fill #7				
79	EMC (%,d.b.)= 12.1			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	36.9	58.6	1.0000	90.2
6.75	34.7	53.1	0.8822	89.2
14.75	33.2	49.7	0.8092	96.0
30.75	27.0	37.0	0.5352	99.3

Bin 317, Fill #11				
80	EMC (%,d.b.)= 10.6			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	40.4	67.9	1.0000	89.8
15.08	32.7	48.6	0.6632	97.0
23.08	30.8	44.5	0.5916	96.9
31.08	28.2	39.3	0.5000	93.7
39.08	25.4	34.0	0.4091	101.2
47.08	22.9	29.6	0.3319	101.9

Bin 319, Fill #1				
81	EMC (%,d.b.)= 13.5			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	37.7	60.6	1.0000	96.3
13.75	30.9	44.8	0.6640	96.9
21.75	27.5	38.0	0.5202	98.0
29.75	25.4	34.0	0.4361	97.0
37.75	21.4	27.2	0.2919	97.3
53.75	19.1	23.6	0.2142	97.0

Bin 319, Fill #2				
82	EMC (%,d.b.)= 16.1			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	32.4	48.0	1.0000	98.3
7.4	29.3	41.5	0.7975	97.5
15.4	27.1	37.3	0.6636	101.4
23.4	21.4	27.2	0.3495	98.6
39.4	19.3	23.9	0.2435	97.6

Bin 319, Fill #3				
83	EMC (%,d.b.)= 12.1			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	38.9	63.8	1.0000	93.2
9.33	37.8	60.9	0.9432	94.0
17.33	31.7	46.4	0.6632	97.9
33.33	25.6	34.5	0.4328	97.0

Bin 319, Fill #4				
84	EMC (%,d.b.)= 13.6			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	37.7	60.6	1.0000	90.3
12.17	33.5	50.3	0.7813	99.5
20.17	27.2	37.4	0.5067	97.9
28.17	24.6	32.6	0.4038	97.4
36.17	23.0	29.8	0.3453	94.8

Bin 319, Fill #5				
85	EMC (%,d.b.)= 14.0			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	38.0	61.3	1.0000	92.5
41.25	23.4	30.5	0.3500	100.3
49.25	22.5	29.1	0.3196	100.0

Bin 319, Fill #6				
86	EMC (%,d.b.)= 10.9			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	36.1	56.6	1.0000	93.8
13.5	18.8	23.2	0.2685	100.3
21.5	17.5	21.2	0.2264	98.4
37.5	15.6	18.4	0.1645	99.8

Bin 319, Fill #7				
87	EMC (%,d.b.)= 12.2			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	37.0	58.8	1.0000	95.5
5.6	34.3	52.2	0.8579	99.5
13.6	32.7	48.6	0.7803	94.8
29.6	24.9	33.2	0.4496	97.6
37.6	20.5	25.8	0.2924	100.4

Bin 319, Fill #11				
88	EMC (%,d.b.)= 8.8			
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	39.6	65.6	1.0000	92.1
12.7	36.6	57.7	0.8608	79.6
20.7	32.7	48.6	0.7000	83.0
28.7	30.9	44.8	0.6331	99.5
36.7	25.0	33.3	0.4313	100.4

Top-layer field data: data sets 89-157

Code numbers bold in upper left-hand corner, location number (i.e., 1, 2, or3) in upper right-hand corner of each data set.

Bin 307, Fill #1				
89	EMC (%, d.b.)=	13.0		**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	23.8	31.2	1.0000	108.8
8	16.1	19.1	0.3373	114.6
16	17.1	20.7	0.4200	103.8
26.5	13.4	15.4	0.1331	108.8

Bin 307, Fill #1				
90	EMC (%, d.b.)=	13.0		**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	29.4	41.6	1.0000	108.8
8	24.3	32.1	0.6698	114.6
16	23.8	31.2	0.6373	103.8
26.5	13.4	15.4	0.0848	108.8

Bin 307, Fill #1				
91	EMC (%, d.b.)=	13.0		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	28.8	40.5	1.0000	108.8
8	21.4	27.2	0.5150	114.6
26.5	13.4	15.4	0.0881	108.8

Bin 307, Fill #2				
92	EMC (%, d.b.)=	10.2		**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	17.0	20.5	1.0000	108.8
8	14.9	17.5	0.7123	108.8
9.7	11.4	12.8	0.2551	108.3

Bin 307, Fill #2				
93	EMC (%, d.b.)=	10.2		**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	18.8	23.2	1.0000	108.8
8	19.1	23.6	1.0311	108.8
9.7	11.4	12.8	0.2012	108.3

Bin 307, Fill #2				
94	EMC (%, d.b.)=	10.2		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	13.9	16.1	1.0000	108.8
9.7	11.4	12.8	0.4430	108.3

Bin 307, Fill #3				
95	EMC (%, d.b.)=	9.3		**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	27.0	37.0	1.0000	107.7
8	24.1	31.7	0.8085	106.7
16	21.1	26.8	0.6305	106.0
24	18.8	23.2	0.5024	107.3
32	17.1	20.7	0.4101	104.3
38.08	12.9	14.8	0.1971	108.7

Bin 307, Fill #3				
96	EMC (%, d.b.)=	9.3		**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	31.2	45.3	1.0000	107.7
8	26.9	36.7	0.7617	106.7
16	23.3	30.3	0.5830	106.0
24	21.4	27.2	0.4966	107.3
32	19.1	23.6	0.3974	104.3
38.08	12.9	14.8	0.1515	108.7

Bin 307, Fill #3				
97	EMC (%, d.b.)=	9.3		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	30.3	43.4	1.0000	107.7
8	24.9	33.1	0.6969	106.7
16	21.4	27.2	0.5240	106.0
24	18.8	23.2	0.4075	107.3
32	17.9	21.8	0.3666	104.3
38.08	12.9	14.8	0.1598	108.7

Bin 307, Fill #4					Bin 307, Fill #4					Bin 307, Fill #4				
98	EMC (%, d.b.)=		11.2	**1**	**99**	EMC (%, d.b.)=		11.2	**2**	**100**	EMC (%, d.b.)=		11.2	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	23.1	30.1	1.0000	105.8	0	31.2	45.3	1.0000	105.8	0	30.3	43.4	1.0000	105.8
16	17.1	20.7	0.5008	105.5	16	26.9	36.7	0.7484	105.5	16	24.9	33.1	0.6791	105.5
24	14.1	16.5	0.2784	109.3	24	23.3	30.3	0.5598	109.3	24	21.4	27.2	0.4959	109.3
26.2	13.0	14.9	0.1972	104.8	26.2	21.4	27.2	0.4686	104.8	26.2	18.8	23.2	0.3725	104.8

Bin 307, Fill #5					Bin 307, Fill #5					Bin 307, Fill #5				
101	EMC (%, d.b.)=		8.4	**1**	**102**	EMC (%, d.b.)=		8.4	**2**	**103**	EMC (%, d.b.)=		8.4	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	18.8	23.2	1.0000	105.3	0	18.8	23.2	1.0000	105.3	0	30.3	43.4	1.0000	105.3
8.4	12.5	14.3	0.3958	103.1	8.4	12.5	14.3	0.3958	103.1	8.4	24.9	33.1	0.7047	103.1

Bin 307, Fill #6					Bin 307, Fill #6					Bin 307, Fill #6				
104	EMC (%, d.b.)=		10.2	**1**	**105**	EMC (%, d.b.)=		10.2	**2**	**106**	EMC (%, d.b.)=		10.2	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	28.3	39.5	1.0000	107.7	0	31.2	45.3	1.0000	107.7	0	30.3	43.4	1.0000	107.7
8	24.1	31.7	0.7328	106.7	8	26.9	36.7	0.7556	106.7	8	24.9	33.1	0.6887	106.7
16	20.2	25.3	0.5140	106.0	16	23.3	30.3	0.5724	106.0	16	21.4	27.2	0.5111	106.0
24	20.0	25.1	0.5069	107.3	24	21.4	27.2	0.4837	107.3	24	18.8	23.2	0.3914	107.3
32	15.3	18.0	0.2677	104.3	32	19.1	23.6	0.3820	104.3	32	17.9	21.8	0.3495	104.3
37.92	14.0	16.3	0.2074	108.7	38.08	12.9	14.8	0.1297	108.7	38.08	12.9	14.8	0.1371	108.7

Bin 307, Fill #11					Bin 307, Fill #11					Bin 307, Fill #11				
107	EMC (%, d.b.)=		8.2	**1**	**108**	EMC (%, d.b.)=		8.2	**2**	**109**	EMC (%, d.b.)=		8.2	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	33.6	50.6	1.0000	103.3	0	31.9	47.0	1.0000	103.3	0	28.1	39.0	1.0000	103.3
8	28.1	39.1	0.7295	104.3	8	31.3	45.6	0.9648	104.3	8	27.3	37.5	0.9507	104.3
16	22.9	29.8	0.5086	105.9	16	24.9	33.1	0.6423	105.9	16	20.8	26.3	0.5885	105.9
24	22.8	29.5	0.5015	105.9	24	21.9	28.1	0.5125	105.9	24	19.0	23.4	0.4939	105.9
32	16.4	19.7	0.2706	86.4	32	20.8	26.3	0.4677	86.4	32	17.5	21.2	0.4231	86.4
37.92	14.8	17.3	0.2153	108.8	38.08	12.4	14.1	0.1522	108.8	38.08	12.4	14.1	0.1915	108.8

Bin 317, Fill #1					Bin 317, Fill #1					Bin 317, Fill #1				
110	EMC (%, d.b.)=		13.1	**1**	**111**	EMC (%, d.b.)=		13.1	**2**	**112**	EMC (%, d.b.)=		13.1	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	21.9	28.1	1.0000	108.6	0	29.1	41.1	1.0000	108.6	0	28.1	39.0	1.0000	108.6
8	15.9	19.0	0.3917	114.6	8	21.2	27.0	0.4960	114.6	8	27.3	37.5	0.9414	114.6
16	15.3	18.0	0.3307	105.4	16	20.8	26.3	0.4729	105.4	16	20.8	26.3	0.5106	105.4
24	12.9	14.8	0.1107	107.9	24	12.9	14.8	0.0592	107.9	24	19.0	23.4	0.3981	107.9
26.55	12.9	14.8	0.1107	107.1	26.55	12.9	14.8	0.0592	107.1	26.55	17.5	21.2	0.3139	107.1

Bin 317, Fill #2					Bin 317, Fill #2					Bin 317, Fill #2				
113	EMC (%, d.b.)=		10.4	**1**	**114**	EMC (%, d.b.)=		10.4	**2**	**115**	EMC (%, d.b.)=		10.4	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	21.9	28.1	1.0000	108.7	0	21.6	27.6	1.0000	108.7	0	22.2	28.5	1.0000	108.7
8	17.5	21.2	0.6133	109.0	8	19.1	23.6	0.7673	109.0	8	17.4	21.0	0.5876	109.0
24	11.1	12.5	0.1192	105.9	24	11.1	12.5	0.1222	105.9	24	11.1	12.5	0.1163	105.9

Bin 317, Fill #3					Bin 317, Fill #3					Bin 317, Fill #3				
116	EMC (%, d.b.)=		9.5	**1**	**117**	EMC (%, d.b.)=		9.5	**2**	**118**	EMC (%, d.b.)=		9.5	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	29.2	41.3	1.0000	107.5	0	31.2	45.3	1.0000	107.5	0	30.4	43.7	1.0000	107.5
8	25.4	34.0	0.7713	107.1	8	26.6	36.2	0.7465	107.1	8	23.8	31.2	0.6350	107.1
16	22.3	28.7	0.6041	107.4	16	23.4	30.5	0.5871	107.4	16	19.0	23.4	0.4067	107.4
24	20.0	25.1	0.4888	104.5	24	20.6	25.9	0.4579	104.5	24	19.9	24.8	0.4487	104.5
32	17.8	21.6	0.3808	107.5	32	18.3	22.4	0.3604	107.5	32	15.3	18.0	0.2499	107.5
41.8	12.9	14.8	0.1651	106.0	41.8	12.9	14.8	0.1467	106.0	41.8	12.9	14.8	0.1537	106.0

Bin 317, Fill #4				
119	EMC (%, d.b.)=		10.9	**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	23.4	30.5	1.0000	104.0
8	21.9	28.1	0.8743	109.7
16	19.9	24.8	0.7106	105.7
24	17.6	21.4	0.5362	106.7
37.17	13.9	16.1	0.2653	99.2

Bin 317, Fill #4				
120	EMC (%, d.b.)=		10.9	**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	24.5	32.4	1.0000	104.0
8	22.3	28.7	0.8297	109.7
16	21.0	26.5	0.7280	105.7
24	17.9	21.8	0.5081	106.7
37.17	13.9	16.1	0.2424	99.2

Bin 317, Fill #4				
121	EMC (%, d.b.)=		10.9	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	24.1	31.7	1.0000	104.0
8	22.7	29.4	0.8900	109.7
16	19.6	24.4	0.6512	105.7
24	18.0	22.0	0.5347	106.7
37.17	13.9	16.1	0.2506	99.2

Bin 317, Fill #5				
122	EMC (%, d.b.)=		8.5	**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	25.8	34.8	1.0000	108.1
8	20.0	25.1	0.6303	108.2
16	17.2	20.8	0.4699	103.3
24	12.1	13.8	0.2007	102.9
26	10.9	12.2	0.1407	101.7

Bin 317, Fill #5				
123	EMC (%, d.b.)=		8.5	**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	19.4	24.0	1.0000	108.1
8	20.0	25.1	1.0667	108.2
16	15.2	17.9	0.6035	103.3
24	17.0	20.5	0.7706	102.9
26	10.9	12.2	0.2381	101.7

Bin 317, Fill #5				
124	EMC (%, d.b.)=		8.5	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	23.9	31.4	1.0000	108.1
8	19.9	24.8	0.7124	108.2
16	17.1	20.7	0.5295	103.3
24	12.2	13.9	0.2368	102.9
26	10.9	12.2	0.1610	101.7

Bin 317, Fill #6				
125	EMC (%, d.b.)=		9.2	**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	23.5	30.8	1.0000	106.3
8	23.0	29.8	0.9577	104.1
16	16.9	20.3	0.5136	107.8
22.43	13.4	15.4	0.2888	108.0

Bin 317, Fill #6				
126	EMC (%, d.b.)=		9.2	**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	25.4	34.0	1.0000	106.3
8	29.9	42.6	1.3459	104.1
16	16.5	19.7	0.4228	107.8
22.43	13.4	15.4	0.2506	108.0

Bin 317, Fill #6				
127	EMC (%, d.b.)=		9.2	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	24.1	31.7	1.0000	106.3
8	25.0	33.3	1.0733	104.1
16	17.4	21.0	0.5265	107.8
22.43	13.4	15.4	0.2769	108.0

Bin 317, Fill #7					Bin 317, Fill #7					Bin 317, Fill #7				
128	EMC (%, d.b.)=		9.9	**1**	**129**	EMC (%, d.b.)=		9.9	**2**	**130**	EMC (%, d.b.)=		9.9	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	29.6	42.1	1.0000	96.3	0	29.9	42.6	1.0000	96.3	0	30.2	43.2	1.0000	96.3
8	25.7	34.5	0.7646	110.0	8	24.9	33.1	0.7083	110.0	8	26.6	36.2	0.7917	110.0
16	22.4	28.9	0.5913	106.7	16	22.3	28.7	0.5750	106.7	16	23.5	30.8	0.6269	106.7
24	16.9	20.3	0.3220	107.6	24	20.4	25.7	0.4822	107.6	24	20.8	26.3	0.4937	107.6
32	16.2	19.3	0.2928	104.5	32	15.8	18.8	0.2711	104.5	32	16.2	19.3	0.2835	104.5
37.65	12.6	14.4	0.1405	102.9	37.65	14.1	16.5	0.2002	102.9	37.65	15.9	19.0	0.2723	102.9

Bin 317, Fill #11					Bin 317, Fill #11					Bin 317, Fill #11				
131	EMC (%, d.b.)=		7.6	**1**	**132**	EMC (%, d.b.)=		7.6	**2**	**133**	EMC (%, d.b.)=		7.6	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	30.3	43.4	1.0000	102.3	0	30.4	43.7	1.0000	102.3	0	33.3	50.0	1.0000	102.3
8	25.9	35.0	0.7650	103.8	8	28.3	39.5	0.8839	103.8	8	28.6	40.0	0.7647	103.8
16	24.3	32.1	0.6850	104.3	16	26.2	35.5	0.7728	104.3	16	24.6	32.6	0.5900	104.3
24	20.3	25.5	0.4988	105.3	24	22.0	28.3	0.5728	105.3	24	22.3	28.7	0.4981	105.3
32	16.9	20.3	0.3536	108.0	32	18.3	22.4	0.4102	108.0	32	18.2	22.2	0.3445	108.0
40	15.8	18.8	0.3119	104.2	40	16.1	19.1	0.3198	104.2	40	17.5	21.2	0.3214	104.2
44.92	11.7	13.3	0.1588	99.6	44.92	11.7	13.3	0.1577	99.6	44.92	11.7	13.3	0.1342	99.6

Bin 319, Fill #1				
134	EMC (%, d.b.)=	13.1		**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	23.1	30.1	1.0000	108.8
8	20.0	25.1	0.7045	114.0
16	17.2	20.8	0.4563	103.2
21.65	13.2	15.3	0.1271	110.0

Bin 319, Fill #1				
135	EMC (%, d.b.)=	13.1		**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	30.0	42.9	1.0000	108.8
8	25.4	34.0	0.7028	114.0
16	21.0	26.5	0.4509	103.2
21.65	13.2	15.3	0.0724	110.0

Bin 319, Fill #1				
136	EMC (%, d.b.)=	13.1		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	25.0	33.3	1.0000	108.8
8	18.7	23.0	0.4898	114.0
16	18.3	22.4	0.4601	103.2
21.65	13.2	15.3	0.1066	110.0

Bin 319, Fill #2				
137	EMC (%, d.b.)=	10.5		**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	19.8	24.6	1.0000	108.7
8	18.0	22.0	0.8141	102.5
16	14.6	17.2	0.4706	109.5
24.7	10.5	11.7	0.0874	109.4

Bin 319, Fill #2				
138	EMC (%, d.b.)=	10.5		**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	25.5	34.3	1.0000	108.7
8	20.3	25.5	0.6296	102.5
16	18.3	22.4	0.5006	109.5
24.7	10.5	11.7	0.0520	109.4

Bin 319, Fill #2				
139	EMC (%, d.b.)=	10.5		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	20.3	25.5	1.0000	108.7
8	16.3	19.5	0.6021	102.5
16	14.3	16.6	0.4092	109.5
24.7	10.5	11.7	0.0825	109.4

Bin 319, Fill #3				
140	EMC (%, d.b.)=	9.1		**1**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	24.6	32.6	1.0000	108.0
8	21.2	27.0	0.7598	107.4
16	20.4	25.7	0.7053	105.1
24	16.9	20.3	0.4750	108.4
29.27	12.9	14.8	0.2405	109.2

Bin 319, Fill #3				
141	EMC (%, d.b.)=	9.1		**2**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	28.6	40.0	1.0000	108.0
8	21.4	27.2	0.5848	107.4
16	20.8	26.3	0.5570	105.1
24	18.3	22.4	0.4303	108.4
29.27	12.9	14.8	0.1829	109.2

Bin 319, Fill #3				
142	EMC (%, d.b.)=	9.1		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	29.0	40.8	1.0000	108.0
8	24.7	32.9	0.7493	107.4
16	19.4	24.0	0.4707	105.1
24	18.2	22.2	0.4135	108.4
29.27	12.9	14.8	0.1784	109.2

Bin 319, Fill #4					Bin 319, Fill #4					Bin 319, Fill #4				
143	EMC (%, d.b.)=	11.3		**1**	**144**	EMC (%, d.b.)=	11.3		**2**	**145**	EMC (%, d.b.)=	11.3		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	26.1	35.3	1.0000	107.0	0	26.7	36.5	1.0000	107.0	0	27.0	37.0	1.0000	107.0
8	24.2	31.9	0.8605	106.0	8	24.3	32.1	0.8278	106.0	8	23.8	31.2	0.7755	106.0
24	19.6	24.4	0.5482	108.0	24	19.4	24.0	0.5051	108.0	24	20.0	25.1	0.5356	108.0
32	17.4	21.0	0.4064	108.5	32	16.3	19.5	0.3263	108.5	32	17.1	20.7	0.3641	108.5
32.13	13.5	15.6	0.1793	104.3	32.13	13.5	15.6	0.1705	104.3	32.13	13.5	15.6	0.1672	104.3

Bin 319, Fill #5					Bin 319, Fill #5					Bin 319, Fill #5				
146	EMC (%, d.b.)=	10.2		**1**	**147**	EMC (%, d.b.)=	10.2		**2**	**148**	EMC (%, d.b.)=	10.2		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	26.9	36.7	1.0000	107.5	0	28.1	39.0	1.0000	107.5	0	29.2	41.3	1.0000	107.5
8	25.1	33.6	0.8806	106.3	8	25.7	34.5	0.8447	106.3	8	25.5	34.3	0.7739	106.3
16	23.9	31.4	0.8008	107.7	16	23.3	30.3	0.6979	107.7	16	23.4	30.5	0.6531	107.7
24	17.9	21.8	0.4378	108.3	24	17.2	20.8	0.3696	108.3	24	19.1	23.6	0.4310	108.3
32	15.3	18.0	0.2958	108.2	32	17.0	20.5	0.3563	108.2	32	16.3	19.5	0.2994	108.2
34.05	11.7	13.3	0.1165	107.9	34.05	11.7	13.3	0.1074	107.9	34.05	11.7	13.3	0.0993	107.9

Bin 319, Fill #6					Bin 319, Fill #6					Bin 319, Fill #6				
149	EMC (%, d.b.)=	10.4		**1**	**150**	EMC (%, d.b.)=	10.4		**2**	**151**	EMC (%, d.b.)=	10.4		**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	24.6	32.6	1.0000	101.0	0	25.7	34.5	1.0000	101.0	0	23.4	30.5	1.0000	101.0
8	21.2	27.0	0.7458	104.0	8	23.9	31.4	0.8724	104.0	8	22.0	28.3	0.8883	104.0
16	16.7	20.1	0.4357	103.4	16	21.8	27.8	0.7228	103.4	16	17.8	21.6	0.5574	103.4
21.9	13.9	16.1	0.2569	101.8	21.9	13.9	16.1	0.2366	101.8	21.9	13.9	16.1	0.2836	101.8

Bin 319, Fill #7					Bin 319, Fill #7					Bin 319, Fill #7				
152	EMC (%, d.b.)=		10.6	**1**	**153**	EMC (%, d.b.)=		10.6	**2**	**154**	EMC (%, d.b.)=		10.6	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	30.0	42.9	1.0000	104.0	0	26.7	36.5	1.0000	104.0	0	28.1	39.0	1.0000	104.0
8	25.7	34.5	0.7407	108.8	8	24.6	32.6	0.8506	108.8	8	25.5	34.3	0.7739	108.8
16	23.7	31.0	0.6311	107.2	16	24.9	33.1	0.8688	107.2	16	22.9	29.6	0.6239	107.2
24	19.4	24.0	0.4155	102.5	24	16.6	19.9	0.3590	102.5	24	18.0	22.0	0.3795	102.5
32	17.9	21.8	0.3472	102.0	32	16.7	20.1	0.3663	102.0	32	16.6	19.9	0.3114	102.0
35.9	13.4	15.4	0.1494	106.9	35.9	13.4	15.4	0.1864	106.9	35.9	13.4	15.4	0.1679	106.9

Bin 319, Fill #11					Bin 319, Fill #11					Bin 319, Fill #11				
155	EMC (%, d.b.)=		8.2	**1**	**156**	EMC (%, d.b.)=		8.2	**2**	**157**	EMC (%, d.b.)=		8.2	**3**
Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F	Time	M.C. (%, w.b.)	M.C. (%, d.b.)	Moisture Ratio d.b.	Temp. Deg. F
0	32.3	47.8	1.0000	103.8	0	37.6	60.3	1.0000	103.8	0	32.6	48.3	1.0000	103.8
8	29.4	41.6	0.8435	104.0	8	32.3	47.8	0.7591	104.0	8	27.0	37.0	0.7172	104.0
16	27.1	37.2	0.7335	105.0	16	26.3	35.7	0.5283	105.0	16	21.8	27.8	0.4894	105.0
24	21.5	27.4	0.4852	106.0	24	24.9	33.1	0.4774	106.0	24	21.0	26.5	0.4570	106.0
32	17.4	21.0	0.3243	96.3	32	21.9	28.1	0.3809	96.3	32	16.9	20.3	0.3008	96.3
41.5	12.5	14.3	0.1531	106.7	41.5	12.5	14.3	0.1162	106.7	41.5	12.5	14.3	0.1510	106.7

Standard error of prediction calculation on the validation data using the model based on the unmodified calibration data.

Code #	Time (h)	Experimental MRAT	Predicted MRAT	Residual	Squared	Experimental M.C.(d.b.)	Predicted M.C. (d.b.)	Residual	Squared			
135	0	1.0000	1.0000	0.0000	0.0000	42.9	42.9	0.0	0.0	Temp =	110	316.3
135	8	0.7028	0.6900	0.0128	0.0002	34.0	33.7	0.4	0.1	R.H. =	28.44	
135	16	0.4509	0.4781	-0.0272	0.0007	26.5	27.4	-0.8	0.7	IMC (w.b.) =	37.7	60.6
135	21.65	0.0724	0.3694	-0.2970	0.0882	15.3	24.1	-8.9	78.8	EMC =	13.1	
										k =	0.04720949	
141	0	1.0000	1.0000	0.0000	0.0000	40.0	40.0	0.0	0.0	Temp =	106.3	314.3
141	8	0.5848	0.7312	-0.1464	0.0214	27.2	31.7	-4.6	20.7	R.H. =	15.97	
141	16	0.5570	0.5366	0.0203	0.0004	26.3	25.7	0.6	0.3	IMC (w.b.) =	38.9	63.8
141	24	0.4303	0.3944	0.0359	0.0013	22.4	21.4	1.0	1.1	EMC =	9.2	
141	29.27	0.1829	0.3221	-0.1392	0.0194	14.8	19.1	-4.4	19.1	k =	0.03982402	
77	0	1.0000	1.0000	0.0000	0.0000	50.8	50.8	0.0	0.0	Temp =	97.9	309.6
77	11	0.8361	0.7274	0.1087	0.0118	44.8	40.7	4.0	16.3	R.H. =	29.97	
77	19	0.4577	0.5786	-0.1209	0.0146	30.8	35.2	-4.5	19.9	IMC (w.b.) =	33.7	50.8
77	27	0.4331	0.4606	-0.0275	0.0008	29.8	30.8	-1.0	1.0	EMC =	13.8	
77	35	0.1901	0.3669	-0.1767	0.0312	20.8	27.4	-6.5	42.5	k =	0.02952473	
68	0	1.0000	1.0000	0.0000	0.0000	60.0	60.0	0.0	0.0	Temp =	98.7	310.1
68	2.42	1.1837	0.9354	0.2482	0.0616	69.1	56.9	12.2	148.2	R.H. =	21.29	
68	10.42	1.0059	0.7528	0.2532	0.0641	60.3	47.9	12.4	153.9	IMC (w.b.) =	37.5	60.0
68	18.42	0.9348	0.6068	0.3280	0.1076	56.9	40.8	16.1	258.2	EMC =	11.0	
68	34.42	0.7218	0.3951	0.3267	0.1067	46.4	30.4	16.0	255.8	k =	0.02779782	

88	0	1.0000	1.0000	0.0000	0.0000	65.6	65.6	0.0	0.0	Temp =	98.6	310.0
88	12.7	0.8608	0.7216	0.1391	0.0194	57.7	49.8	7.9	62.5	R.H. =	14.65	
88	20.7	0.7000	0.5889	0.1112	0.0124	48.6	42.3	6.3	39.9	IMC (w.b.) =	39.6	65.6
88	28.7	0.6331	0.4808	0.1522	0.0232	44.8	36.1	8.6	74.8	EMC =	8.8	
88	36.7	0.4313	0.3928	0.0385	0.0015	33.3	31.1	2.2	4.8	k =	0.02624698	

154	0	1.0000	1.0000	0.0000	0.0000	39.0	39.0	0.0	0.0	Temp =	104.4	313.2
154	8	0.7739	0.7526	0.0213	0.0005	34.3	32.0	2.3	5.4	R.H. =	19.97	
154	16	0.6239	0.5683	0.0556	0.0031	29.6	26.7	2.9	8.4	IMC (w.b.) =	37.1	58.9
154	24	0.3795	0.4297	-0.0502	0.0025	22.0	22.8	-0.8	0.6	EMC =	10.6	
154	32	0.3114	0.3251	-0.0137	0.0002	19.9	19.8	0.1	0.0	k =	0.03615535	
154	35.9	0.1679	0.2839	-0.1160	0.0134	15.4	18.6	-3.2	10.3			

98	0	1.0000	1.0000	0.0000	0.0000	30.1	30.1	0.0	0.0	Temp =	106.8	314.6
98	16	0.5008	0.5371	-0.0362	0.0013	20.7	21.3	-0.7	0.4	R.H. =	21.92	
98	24	0.2784	0.3948	-0.1165	0.0136	16.5	18.6	-2.2	4.7	IMC (w.b.) =	35.4	54.8
98	26.2	0.1972	0.3629	-0.1657	0.0274	14.9	18.0	-3.1	9.6	EMC =	11.2	
										k =	0.039774	

157	0	1.0000	1.0000	0.0000	0.0000	48.3	48.3	0.0	0.0	Temp =	102.8	312.3
157	8	0.7172	0.7716	-0.0544	0.0030	37.0	39.2	-2.2	4.7	R.H. =	12.98	
157	16	0.4894	0.5972	-0.1078	0.0116	27.8	32.1	-4.3	18.6	IMC (w.b.) =	39.6	65.6
157	24	0.4570	0.4627	-0.0058	0.0000	26.5	26.7	-0.2	0.0	EMC =	8.2	
157	32	0.3008	0.3588	-0.0580	0.0034	20.3	22.6	-2.3	5.3	k =	0.03298438	
157	41.5	0.1510	0.2654	-0.1144	0.0131	14.3	18.8	-4.6	20.8			

94	0	1.0000	1.0000	0.0000	0.0000	16.1	16.1	0.0	0.0	Temp =	108	315.2
94	9.7	0.4430	0.6806	-0.2376	0.0564	12.8	14.2	-1.4	2.0	R.H. =	19.04	
										IMC (w.b.) =	32.7	48.6
										EMC =	10.2	
										k =	0.04043526	

133	0	1.0000	1.0000	0.0000	0.0000	50.0	50.0	0.0	0.0	Temp =	102.9	312.4
133	8	0.7647	0.7718	-0.0072	0.0001	40.0	38.6	1.4	2.0	R.H. =	11.62	
133	16	0.5900	0.5975	-0.0076	0.0001	32.6	29.9	2.7	7.5	IMC (w.b.) =	40.4	67.9
133	24	0.4981	0.4631	0.0350	0.0012	28.7	23.2	5.6	31.0	EMC =	7.6	
133	32	0.3445	0.3592	-0.0147	0.0002	22.2	18.0	4.2	18.0	k =	0.03294624	
133	40	0.3214	0.2788	0.0427	0.0018	21.2	13.9	7.3	53.1			
133	44.92	0.1342	0.2386	-0.1043	0.0109	13.3	11.9	1.4	1.9			

138	0	1.0000	1.0000	0.0000	0.0000	34.3	34.3	0.0	0.0	Temp =	107.3	314.8
138	8	0.6296	0.7329	-0.1033	0.0107	25.5	27.9	-2.4	6.0	R.H. =	19.75	
138	16	0.5006	0.5391	-0.0385	0.0015	22.4	23.3	-0.9	0.8	IMC (w.b.) =	32.5	48.1
138	24.7	0.0520	0.3866	-0.3347	0.1120	11.7	19.7	-7.9	63.0	EMC =	10.5	
										k =	0.03953046	

69	0	1.0000	1.0000	0.0000	0.0000	54.8	54.8	0.0	0.0	Temp =	97.5	309.4
69	11	0.7181	0.7404	-0.0223	0.0005	43.4	44.3	-0.9	0.8	R.H. =	32.08	
69	19	0.6723	0.5964	0.0759	0.0058	41.6	38.5	3.1	9.4	IMC (w.b.) =	35.4	54.8
69	27	0.3109	0.4808	-0.1699	0.0289	27.0	33.8	-6.9	47.2	EMC =	14.4	
69	35	0.4159	0.3878	0.0281	0.0008	31.2	30.1	1.1	1.3	k =	0.02788891	

128	0	1.0000	1.0000	0.0000	0.0000	42.1	42.1	0.0	0.0	Temp =	106.6	314.4
128	8	0.7646	0.7268	0.0377	0.0014	34.5	33.3	1.2	1.5	R.H. =	18.03	
128	16	0.5913	0.5302	0.0610	0.0037	28.9	27.0	2.0	3.9	IMC (w.b.) =	39.4	65.0
128	24	0.3220	0.3874	-0.0654	0.0043	20.3	22.4	-2.1	4.4	EMC =	9.9	
128	32	0.2928	0.2833	0.0095	0.0001	19.3	19.0	0.3	0.1	k =	0.04059123	
128	37.65	0.1405	0.2272	-0.0867	0.0075	14.4	17.2	-2.8	7.8			

104	0	1.0000	1.0000	0.0000	0.0000	39.5	39.5	0.0	0.0	Temp =	101.6	311.7
104	8	0.7328	0.7720	-0.0391	0.0015	31.7	32.8	-1.1	1.3	R.H. =	18.68	
104	16	0.5140	0.5978	-0.0838	0.0070	25.3	27.7	-2.4	6.0	IMC (w.b.) =	34.4	52.5
104	24	0.5069	0.4634	0.0435	0.0019	25.1	23.8	1.3	1.7	EMC =	10.2	
104	32	0.2677	0.3595	-0.0917	0.0084	18.0	20.7	-2.7	7.1	k =	0.03292371	
104	37.92	0.2074	0.2980	-0.0906	0.0082	16.3	18.9	-2.6	6.9			

146	0	1.0000	1.0000	0.0000	0.0000	36.7	36.7	0.0	0.0	Temp =	106.3	314.3
146	8	0.8806	0.7326	0.1480	0.0219	33.6	29.6	3.9	15.4	R.H. =	18.98	
146	16	0.8008	0.5386	0.2622	0.0687	31.4	24.5	6.9	48.3	IMC (w.b.) =	38.0	61.2
146	24	0.4378	0.3966	0.0412	0.0017	21.8	20.7	1.1	1.2	EMC =	10.2	
146	32	0.2958	0.2922	0.0035	0.0000	18.0	18.0	0.1	0.0	k =	0.03958664	
146	34.05	0.1165	0.2703	-0.1538	0.0236	13.3	17.4	-4.1	16.7			

101	0	1.0000	1.0000	0.0000	0.0000	23.2	23.2	0.0	0.0	Temp =	105.7	313.9
101	8.4	0.3958	0.7295	-0.3338	0.1114	14.3	19.2	-4.9	24.4	R.H. =	13.7	
										IMC (w.b.) =	36.3	56.9
										EMC =	8.4	
										k =	0.03822195	

115	0	1.0000	1.0000	0.0000	0.0000	28.5	28.5	0.0	0.0	Temp =	108.4	315.4
115	8	0.5876	0.7224	-0.1348	0.0182	21.0	23.5	-2.4	5.9	R.H. =	19.59	
115	24	0.1163	0.3804	-0.2641	0.0698	12.5	17.3	-4.8	22.8	IMC (w.b.) =	33.6	50.6
										EMC =	10.4	
										k =	0.04137087	

87	0	1.0000	1.0000	0.0000	0.0000	58.8	58.8	0.0	0.0	Temp =	97.5	309.4
87	5.6	0.8579	0.8632	-0.0053	0.0000	52.2	52.4	-0.2	0.1	R.H. =	24.79	
87	13.6	0.7803	0.7015	0.0788	0.0062	48.6	44.9	3.7	13.6	IMC (w.b.) =	37.1	58.9
87	29.6	0.4496	0.4647	-0.0150	0.0002	33.2	33.8	-0.7	0.5	EMC =	12.2	
87	37.6	0.2924	0.3785	-0.0861	0.0074	25.8	29.8	-4.0	16.0	k =	0.02664649	

71	0	1.0000	1.0000	0.0000	0.0000	52.5	52.5	0.0	0.0	Temp =	98.3	309.8
71	9.08	0.7443	0.7695	-0.0252	0.0006	41.8	42.9	-1.1	1.1	R.H. =	20.27	
71	25.08	0.5125	0.4880	0.0246	0.0006	32.1	31.1	1.0	1.0	IMC (w.b.) =	34.4	52.5
71	33.08	0.3785	0.3890	-0.0105	0.0001	26.5	27.0	-0.5	0.2	EMC =	10.7	
71	41.08	0.2378	0.3103	-0.0724	0.0052	20.7	23.7	-3.0	9.3	k =	0.02939933	

80	0	1.0000	1.0000	0.0000	0.0000	67.9	67.9	0.0	0.0	Temp =	97.8	309.6
80	15.08	0.6632	0.6966	-0.0334	0.0011	48.6	50.5	-1.9	3.6	R.H. =	19.73	
80	23.08	0.5916	0.5762	0.0154	0.0002	44.5	43.6	0.9	0.8	IMC (w.b.) =	40.4	67.9
80	31.08	0.5000	0.4769	0.0232	0.0005	39.3	37.9	1.4	1.8	EMC =	10.6	
80	39.08	0.4091	0.3948	0.0143	0.0002	34.0	33.2	0.8	0.7	k =	0.02452873	
80	47.08	0.3319	0.3270	0.0049	0.0000	29.6	29.3	0.3	0.1			

81	0	1.0000	1.0000	0.0000	0.0000	60.6	60.6	0.0	0.0	Temp =	97.2	309.2
81	13.75	0.6640	0.7069	-0.0429	0.0018	44.8	46.8	-2.0	4.1	R.H. =	29.12	
81	21.75	0.5202	0.5790	-0.0588	0.0035	38.0	40.8	-2.8	7.7	IMC (w.b.) =	37.7	60.6
81	29.75	0.4361	0.4745	-0.0384	0.0015	34.0	35.9	-1.8	3.3	EMC =	13.5	
81	37.75	0.2919	0.3891	-0.0972	0.0094	27.2	31.8	-4.6	21.0	k =	0.02578759	
81	53.75	0.2142	0.2618	-0.0476	0.0023	23.6	25.8	-2.3	5.1			

112	0	1.0000	1.0000	0.0000	0.0000	39.0	39.0	0.0	0.0	Temp =	110	316.3
112	8	0.9414	0.7022	0.2392	0.0572	37.5	31.3	6.2	38.4	R.H. =	28.27	
112	16	0.5106	0.4951	0.0155	0.0002	26.3	25.9	0.4	0.2	IMC (w.b.) =	35.3	54.5
112	24	0.3981	0.3496	0.0484	0.0023	23.4	22.1	1.3	1.6	EMC =	13.1	
112	26.55	0.3139	0.3130	0.0009	0.0000	21.2	21.2	0.0	0.0	k =	0.04497755	

132	0	1.0000	1.0000	0.0000	0.0000	43.7	43.7	0.0	0.0	Temp =	102.9	312.4
132	8	0.8839	0.7718	0.1121	0.0126	39.5	35.5	4.0	16.3	R.H. =	11.62	
132	16	0.7728	0.5975	0.1753	0.0307	35.5	29.2	6.3	39.8	IMC (w.b.) =	40.4	67.9
132	24	0.5728	0.4631	0.1097	0.0120	28.3	24.3	3.9	15.5	EMC =	7.6	
132	32	0.4102	0.3592	0.0509	0.0026	22.4	20.6	1.8	3.3	k =	0.03294624	
132	40	0.3198	0.2788	0.0410	0.0017	19.1	17.7	1.4	2.1			
132	44.92	0.1577	0.2386	-0.0809	0.0065	13.3	16.2	-3.0	8.7			

91	0	1.0000	1.0000	0.0000	0.0000	40.5	40.5	0.0	0.0	Temp =	110.1	316.4
91	8	0.5150	0.7034	-0.1884	0.0355	27.2	32.4	-5.2	27.1	R.H. =	28.15	
91	26.5	0.0881	0.3155	-0.2275	0.0517	15.4	21.7	-6.3	39.7	IMC (w.b.) =	34.8	53.4
										EMC =	13.0	
										k =	0.04475302	

123	0	1.0000	1.0000	0.0000	0.0000	24.0	24.0	0.0	0.0	Temp =	106.4	314.3
123	8	1.0667	0.7373	0.3294	0.1085	25.1	19.9	5.1	26.3	R.H. =	13.86	
123	16	0.6035	0.5455	0.0580	0.0034	17.9	16.9	0.9	0.8	IMC (w.b.) =	33.7	50.8
123	24	0.7706	0.4041	0.3664	0.1343	20.5	14.7	5.7	32.7	EMC =	8.5	
123	26	0.2381	0.3750	-0.1369	0.0188	12.2	14.3	-2.1	4.4	k =	0.03877797	

137	0	1.0000	1.0000	0.0000	0.0000	24.6	24.6	0.0	0.0	Temp =	107.3	314.8
137	8	0.8141	0.7329	0.0812	0.0066	22.0	20.9	1.2	1.3	R.H. =	19.75	
137	16	0.4706	0.5391	-0.0685	0.0047	17.2	18.1	-1.0	0.9	IMC (w.b.) =	32.5	48.1
137	24.7	0.0874	0.3866	-0.2992	0.0895	11.7	15.9	-4.2	17.7	EMC =	10.5	
										k =	0.03953046	

152	0	1.0000	1.0000	0.0000	0.0000	42.9	42.9	0.0	0.0	Temp =	104.4	313.2
152	8	0.7407	0.7526	-0.0119	0.0001	34.5	34.9	-0.4	0.1	R.H. =	19.97	
152	16	0.6311	0.5683	0.0628	0.0039	31.0	28.9	2.0	4.2	IMC (w.b.) =	37.1	58.9
152	24	0.4155	0.4297	-0.0142	0.0002	24.0	24.5	-0.4	0.2	EMC =	10.6	
152	32	0.3472	0.3251	0.0221	0.0005	21.8	21.1	0.7	0.5	k =	0.03615535	
152	35.9	0.1494	0.2839	-0.1345	0.0181	15.4	19.7	-4.3	18.6			

131	0	1.0000	1.0000	0.0000	0.0000	43.4	43.4	0.0	0.0	Temp =	102.9	312.4
131	8	0.7650	0.7718	-0.0069	0.0000	35.0	35.3	-0.3	0.1	R.H. =	11.62	
131	16	0.6850	0.5975	0.0875	0.0077	32.1	29.0	3.1	9.7	IMC (w.b.) =	40.4	67.9
131	24	0.4988	0.4631	0.0357	0.0013	25.5	24.2	1.3	1.6	EMC =	7.6	
131	32	0.3536	0.3592	-0.0056	0.0000	20.3	20.5	-0.2	0.1	k =	0.03294624	
131	40	0.3119	0.2788	0.0331	0.0011	18.8	17.6	1.2	1.3			
131	44.92	0.1588	0.2386	-0.0797	0.0064	13.3	16.2	-2.9	8.4			

97	0	1.0000	1.0000	0.0000	0.0000	43.4	43.4	0.0	0.0	Temp =	106.4	314.3
97	8	0.6969	0.7321	-0.0352	0.0012	33.1	34.3	-1.2	1.4	R.H. =	16.17	
97	16	0.5240	0.5380	-0.0140	0.0002	27.2	27.6	-0.5	0.2	IMC (w.b.) =	37.5	60.0
97	24	0.4075	0.3959	0.0116	0.0001	23.2	22.8	0.4	0.2	EMC =	9.3	
97	32	0.3666	0.2915	0.0751	0.0056	21.8	19.2	2.6	6.7	k =	0.03966263	
97	38.08	0.1598	0.2312	-0.0714	0.0051	14.8	17.2	-2.4	5.8			

76	0	1.0000	1.0000	0.0000	0.0000	55.4	55.4	0.0	0.0	Temp =	98.8	310.1
76	8.83	0.5904	0.7769	-0.1864	0.0348	38.5	46.2	-7.7	59.3	R.H. =	31.14	
76	16.83	0.6028	0.6197	-0.0169	0.0003	39.0	39.7	-0.7	0.5	IMC (w.b.) =	35.6	55.4
76	24.83	0.4945	0.4947	-0.0002	0.0000	34.5	34.5	0.0	0.0	EMC =	14.1	
76	32.83	0.3977	0.3952	0.0024	0.0000	30.5	30.4	0.1	0.0	k =	0.02912291	
76	40.83	0.4144	0.3159	0.0985	0.0097	31.2	27.1	4.1	16.5			
				SSE =	1.9861			SSE =	2209.1			
				MSE =	0.0132			MSE =	14.6			
				SEP =	0.1147			RMSE =	3.8			

Standard error of prediction calculation on the validation data using the model baed on the jackknife-modified calibration data.

Code #	Time (h)	Experimental MRAT	Predicted MRAT	Residual	Squared	Experimental M.C. (d.b.)	Predicted M.C. (d.b.)	Residual	Squared			
135	0	1.0000	1.0000	0.0000	0.0000	42.9	42.9	0.0	0.0	Temp =	110	316.3
135	8	0.7028	0.6965	0.0063	0.0000	34.0	33.9	0.2	0.0	R.H. =	28.44	
135	16	0.4509	0.4904	-0.0395	0.0016	26.5	27.7	-1.2	1.4	IMC (w.b.) =	37.7	60.6
135	21.65	0.0724	0.3837	-0.3113	0.0969	15.3	24.6	-9.3	86.5	EMC =	13.1	
										k =	0.04729344	
141	0	1.0000	1.0000	0.0000	0.0000	40.0	40.0	0.0	0.0	Temp =	106.3	314.3
141	8	0.5848	0.7351	-0.1503	0.0226	27.2	31.9	-4.7	21.9	R.H. =	15.97	
141	16	0.5570	0.5454	0.0116	0.0001	26.3	26.0	0.3	0.1	IMC (w.b.) =	38.9	63.8
141	24	0.4303	0.4060	0.0243	0.0006	22.4	21.7	0.7	0.5	EMC =	9.2	
141	29.27	0.1829	0.3346	-0.1518	0.0230	14.8	19.5	-4.8	22.7	k =	0.04023955	
77	0	1.0000	1.0000	0.0000	0.0000	50.8	50.8	0.0	0.0	Temp =	97.9	309.6
77	11	0.8361	0.7255	0.1106	0.0122	44.8	40.7	4.1	16.9	R.H. =	29.97	
77	19	0.4577	0.5782	-0.1206	0.0145	30.8	35.2	-4.4	19.8	IMC (w.b.) =	33.7	50.8
77	27	0.4331	0.4619	-0.0288	0.0008	29.8	30.9	-1.0	1.1	EMC =	13.8	
77	35	0.1901	0.3694	-0.1793	0.0322	20.8	27.5	-6.6	43.8	k =	0.03072813	
68	0	1.0000	1.0000	0.0000	0.0000	60.0	60.0	0.0	0.0	Temp =	98.7	310.1
68	2.42	1.1837	0.9338	0.2498	0.0624	69.1	56.8	12.3	150.1	R.H. =	21.29	
68	10.42	1.0059	0.7515	0.2544	0.0647	60.3	47.9	12.5	155.4	IMC (w.b.) =	37.5	60.0
68	18.42	0.9348	0.6073	0.3276	0.1073	56.9	40.8	16.0	257.5	EMC =	11.0	
68	34.42	0.7218	0.3987	0.3231	0.1044	46.4	30.6	15.8	250.2	k =	0.0288431	

88	0	1.0000	1.0000	0.0000	0.0000	65.6	65.6	0.0	0.0	Temp =	98.6	310.0
88	12.7	0.8608	0.7210	0.1398	0.0195	57.7	49.8	7.9	63.1	R.H. =	14.65	
88	20.7	0.7000	0.5900	0.1101	0.0121	48.6	42.3	6.3	39.1	IMC (w.b.) =	39.6	65.6
88	28.7	0.6331	0.4836	0.1495	0.0223	44.8	36.3	8.5	72.1	EMC =	8.8	
88	36.7	0.4313	0.3969	0.0344	0.0012	33.3	31.4	1.9	3.8	k =	0.02721995	

154	0	1.0000	1.0000	0.0000	0.0000	39.0	39.0	0.0	0.0	Temp =	104.4	313.2
154	8	0.7739	0.7541	0.0198	0.0004	34.3	32.0	2.3	5.2	R.H. =	19.97	
154	16	0.6239	0.5734	0.0505	0.0025	29.6	26.9	2.7	7.6	IMC (w.b.) =	37.1	58.9
154	24	0.3795	0.4374	-0.0579	0.0034	22.0	23.0	-1.0	1.0	EMC =	10.6	
154	32	0.3114	0.3343	-0.0229	0.0005	19.9	20.1	-0.2	0.0	k =	0.03690782	
154	35.9	0.1679	0.2934	-0.1255	0.0158	15.4	18.9	-3.5	12.1			

98	0	1.0000	1.0000	0.0000	0.0000	30.1	30.1	0.0	0.0	Temp =	106.8	314.6
98	16	0.5008	0.5434	-0.0425	0.0018	20.7	21.4	-0.8	0.6	R.H. =	21.92	
98	24	0.2784	0.4038	-0.1254	0.0157	16.5	18.8	-2.3	5.5	IMC (w.b.) =	35.4	54.8
98	26.2	0.1972	0.3723	-0.1750	0.0306	14.9	18.2	-3.3	10.8	EMC =	11.2	
										k =	0.04048194	

157	0	1.0000	1.0000	0.0000	0.0000	48.3	48.3	0.0	0.0	Temp =	102.8	312.3
157	8	0.7172	0.7728	-0.0556	0.0031	37.0	39.2	-2.2	4.9	R.H. =	12.98	
157	16	0.4894	0.6019	-0.1125	0.0127	27.8	32.3	-4.5	20.2	IMC (w.b.) =	39.6	65.6
157	24	0.4570	0.4701	-0.0131	0.0002	26.5	27.0	-0.5	0.3	EMC =	8.2	
157	32	0.3008	0.3678	-0.0670	0.0045	20.3	22.9	-2.7	7.1	k =	0.03369656	
157	41.5	0.1510	0.2753	-0.1243	0.0154	14.3	19.2	-5.0	24.6			

94	0	1.0000	1.0000	0.0000	0.0000	16.1	16.1	0.0	0.0	Temp =	108	315.2
94	9.7	0.4430	0.6828	-0.2398	0.0575	12.8	14.2	-1.4	2.0	R.H. =	19.04	
										IMC (w.b.) =	32.7	48.6
										EMC =	10.2	
										k =	0.04131708	

133	0	1.0000	1.0000	0.0000	0.0000	50.0	50.0	0.0	0.0	Temp =	102.9	312.4
133	8	0.7647	0.7734	-0.0087	0.0001	40.0	38.7	1.4	1.8	R.H. =	11.62	
133	16	0.5900	0.6027	-0.0128	0.0002	32.6	30.1	2.5	6.1	IMC (w.b.) =	40.4	67.9
133	24	0.4981	0.4711	0.0271	0.0007	28.7	23.6	5.2	26.7	EMC =	7.6	
133	32	0.3445	0.3688	-0.0243	0.0006	22.2	18.4	3.8	14.2	k =	0.03359963	
133	40	0.3214	0.2892	0.0323	0.0010	21.2	14.5	6.8	45.8			
133	44.92	0.1342	0.2491	-0.1149	0.0132	13.3	12.5	0.8	0.7			

138	0	1.0000	1.0000	0.0000	0.0000	34.3	34.3	0.0	0.0	Temp =	107.3	314.8
138	8	0.6296	0.7338	-0.1042	0.0109	25.5	27.9	-2.5	6.1	R.H. =	19.75	
138	16	0.5006	0.5435	-0.0429	0.0018	22.4	23.4	-1.0	1.0	IMC (w.b.) =	32.5	48.1
138	24.7	0.0520	0.3936	-0.3416	0.1167	11.7	19.8	-8.1	65.6	EMC =	10.5	
										k =	0.04046725	

69	0	1.0000	1.0000	0.0000	0.0000	54.8	54.8	0.0	0.0	Temp =	97.5	309.4
69	11	0.7181	0.7384	-0.0203	0.0004	43.4	44.3	-0.8	0.7	R.H. =	32.08	
69	19	0.6723	0.5959	0.0765	0.0058	41.6	38.5	3.1	9.6	IMC (w.b.) =	35.4	54.8
69	27	0.3109	0.4818	-0.1710	0.0292	27.0	33.9	-6.9	47.8	EMC =	14.4	
69	35	0.4159	0.3901	0.0258	0.0007	31.2	30.2	1.0	1.1	k =	0.02904538	

128	0	1.0000	1.0000	0.0000	0.0000	42.1	42.1	0.0	0.0	Temp =	106.6	314.4
128	8	0.7646	0.7313	0.0333	0.0011	34.5	33.5	1.1	1.2	R.H. =	18.03	
128	16	0.5913	0.5398	0.0515	0.0027	28.9	27.3	1.7	2.8	IMC (w.b.) =	39.4	65.0
128	24	0.3220	0.3998	-0.0778	0.0061	20.3	22.8	-2.5	6.3	EMC =	9.9	
128	32	0.2928	0.2968	-0.0040	0.0000	19.3	19.5	-0.1	0.0	k =	0.04092417	
128	37.65	0.1405	0.2407	-0.1002	0.0100	14.4	17.7	-3.2	10.4			

104	0	1.0000	1.0000	0.0000	0.0000	39.5	39.5	0.0	0.0	Temp =	101.6	311.7
104	8	0.7328	0.7711	-0.0383	0.0015	31.7	32.8	-1.1	1.2	R.H. =	18.68	
104	16	0.5140	0.5993	-0.0853	0.0073	25.3	27.8	-2.5	6.2	IMC (w.b.) =	34.4	52.5
104	24	0.5069	0.4670	0.0398	0.0016	25.1	23.9	1.2	1.4	EMC =	10.2	
104	32	0.2677	0.3647	-0.0969	0.0094	18.0	20.9	-2.8	7.9	k =	0.03398313	
104	37.92	0.2074	0.3039	-0.0965	0.0093	16.3	19.1	-2.8	7.9			

146	0	1.0000	1.0000	0.0000	0.0000	36.7	36.7	0.0	0.0	Temp =	106.3	314.3
146	8	0.8806	0.7359	0.1447	0.0209	33.6	29.7	3.8	14.7	R.H. =	18.98	
146	16	0.8008	0.5465	0.2543	0.0647	31.4	24.7	6.7	45.4	IMC (w.b.) =	38.0	61.2
146	24	0.4378	0.4072	0.0305	0.0009	21.8	21.0	0.8	0.6	EMC =	10.2	
146	32	0.2958	0.3041	-0.0084	0.0001	18.0	18.3	-0.2	0.1	k =	0.04009831	
146	34.05	0.1165	0.2823	-0.1657	0.0275	13.3	17.7	-4.4	19.4			

101	0	1.0000	1.0000	0.0000	0.0000	23.2	23.2	0.0	0.0	Temp =	105.7	313.9
101	8.4	0.3958	0.7317	-0.3360	0.1129	14.3	19.2	-5.0	24.8	R.H. =	13.7	
										IMC (w.b.) =	36.3	56.9
										EMC =	8.4	
										k =	0.0389378	

115	0	1.0000	1.0000	0.0000	0.0000	28.5	28.5	0.0	0.0	Temp =	108.4	315.4
115	8	0.5876	0.7245	-0.1369	0.0187	21.0	23.5	-2.5	6.1	R.H. =	19.59	
115	24	0.1163	0.3890	-0.2727	0.0744	12.5	17.4	-4.9	24.3	IMC (w.b.) =	33.6	50.6
										EMC =	10.4	
										k =	0.0421427	

87	0	1.0000	1.0000	0.0000	0.0000	58.8	58.8	0.0	0.0	Temp =	97.5	309.4
87	5.6	0.8579	0.8610	-0.0030	0.0000	52.2	52.3	-0.1	0.0	R.H. =	24.79	
87	13.6	0.7803	0.7000	0.0803	0.0064	48.6	44.8	3.8	14.1	IMC (w.b.) =	37.1	58.9
87	29.6	0.4496	0.4662	-0.0165	0.0003	33.2	33.9	-0.8	0.6	EMC =	12.2	
87	37.6	0.2924	0.3812	-0.0888	0.0079	25.8	30.0	-4.1	17.0	k =	0.027748	

71	0	1.0000	1.0000	0.0000	0.0000	52.5	52.5	0.0	0.0	Temp =	98.3	309.8
71	9.08	0.7443	0.7675	-0.0232	0.0005	41.8	42.8	-1.0	1.0	R.H. =	20.27	
71	25.08	0.5125	0.4892	0.0233	0.0005	32.1	31.2	1.0	0.9	IMC (w.b.) =	34.4	52.5
71	33.08	0.3785	0.3917	-0.0132	0.0002	26.5	27.1	-0.6	0.3	EMC =	10.7	
71	41.08	0.2378	0.3139	-0.0761	0.0058	20.7	23.9	-3.2	10.2	k =	0.03056714	

80	0	1.0000	1.0000	0.0000	0.0000	67.9	67.9	0.0	0.0	Temp =	97.8	309.6
80	15.08	0.6632	0.6958	-0.0326	0.0011	48.6	50.5	-1.9	3.4	R.H. =	19.73	
80	23.08	0.5916	0.5770	0.0147	0.0002	44.5	43.6	0.9	0.7	IMC (w.b.) =	40.4	67.9
80	31.08	0.5000	0.4791	0.0209	0.0004	39.3	38.0	1.2	1.5	EMC =	10.6	
80	39.08	0.4091	0.3982	0.0109	0.0001	34.0	33.4	0.7	0.4	k =	0.02550676	
80	47.08	0.3319	0.3313	0.0006	0.0000	29.6	29.6	0.1	0.0			

81	0	1.0000	1.0000	0.0000	0.0000	60.6	60.6	0.0	0.0	Temp =	97.2	309.2
81	13.75	0.6640	0.7053	-0.0412	0.0017	44.8	46.7	-1.9	3.8	R.H. =	29.12	
81	21.75	0.5202	0.5788	-0.0586	0.0034	38.0	40.8	-2.8	7.6	IMC (w.b.) =	37.7	60.6
81	29.75	0.4361	0.4757	-0.0396	0.0016	34.0	35.9	-1.9	3.5	EMC =	13.5	
81	37.75	0.2919	0.3915	-0.0996	0.0099	27.2	31.9	-4.7	22.1	k =	0.02687655	
81	53.75	0.2142	0.2658	-0.0516	0.0027	23.6	26.0	-2.4	5.9			

112	0	1.0000	1.0000	0.0000	0.0000	39.0	39.0	0.0	0.0	Temp =	110	316.3
112	8	0.9414	0.7065	0.2349	0.0552	37.5	31.4	6.1	37.1	R.H. =	28.27	
112	16	0.5106	0.5044	0.0062	0.0000	26.3	26.2	0.2	0.0	IMC (w.b.) =	35.3	54.5
112	24	0.3981	0.3614	0.0367	0.0013	23.4	22.5	1.0	0.9	EMC =	13.1	
112	26.55	0.3139	0.3252	-0.0113	0.0001	21.2	21.5	-0.3	0.1	k =	0.04542527	

132	0	1.0000	1.0000	0.0000	0.0000	43.7	43.7	0.0	0.0	Temp =	102.9	312.4
132	8	0.8839	0.7734	0.1105	0.0122	39.5	35.5	4.0	15.8	R.H. =	11.62	
132	16	0.7728	0.6027	0.1701	0.0289	35.5	29.4	6.1	37.5	IMC (w.b.) =	40.4	67.9
132	24	0.5728	0.4711	0.1017	0.0104	28.3	24.6	3.6	13.3	EMC =	7.6	
132	32	0.4102	0.3688	0.0413	0.0017	22.4	20.9	1.5	2.1	k =	0.03359963	
132	40	0.3198	0.2892	0.0306	0.0009	19.1	18.1	1.1	1.1			
132	44.92	0.1577	0.2491	-0.0914	0.0084	13.3	16.6	-3.3	11.1			

91	0	1.0000	1.0000	0.0000	0.0000	40.5	40.5	0.0	0.0	Temp =	110.1	316.4
91	8	0.5150	0.7075	-0.1924	0.0370	27.2	32.5	-5.3	28.2	R.H. =	28.15	
91	26.5	0.0881	0.3272	-0.2392	0.0572	15.4	22.0	-6.6	43.8	IMC (w.b.) =	34.8	53.4
										EMC =	13.0	
										k =	0.04525387	

123	0	1.0000	1.0000	0.0000	0.0000	24.0	24.0	0.0	0.0	Temp =	106.4	314.3
123	8	1.0667	0.7384	0.3283	0.1078	25.1	19.9	5.1	26.1	R.H. =	13.86	
123	16	0.6035	0.5502	0.0533	0.0028	17.9	17.0	0.8	0.7	IMC (w.b.) =	33.7	50.8
123	24	0.7706	0.4113	0.3593	0.1291	20.5	14.9	5.6	31.4	EMC =	8.5	
123	26	0.2381	0.3826	-0.1445	0.0209	12.2	14.4	-2.2	4.9	k =	0.03965963	

137	0	1.0000	1.0000	0.0000	0.0000	24.6	24.6	0.0	0.0	Temp =	107.3	314.8
137	8	0.8141	0.7338	0.0803	0.0064	22.0	20.9	1.1	1.3	R.H. =	19.75	
137	16	0.4706	0.5435	-0.0729	0.0053	17.2	18.2	-1.0	1.0	IMC (w.b.) =	32.5	48.1
137	24.7	0.0874	0.3936	-0.3062	0.0937	11.7	16.0	-4.3	18.5	EMC =	10.5	
										k =	0.04046725	

152	0	1.0000	1.0000	0.0000	0.0000	42.9	42.9	0.0	0.0	Temp =	104.4	313.2
152	8	0.7407	0.7541	-0.0134	0.0002	34.5	34.9	-0.4	0.2	R.H. =	19.97	
152	16	0.6311	0.5734	0.0577	0.0033	31.0	29.1	1.9	3.5	IMC (w.b.) =	37.1	58.9
152	24	0.4155	0.4374	-0.0219	0.0005	24.0	24.7	-0.7	0.5	EMC =	10.6	
152	32	0.3472	0.3343	0.0129	0.0002	21.8	21.4	0.4	0.2	k =	0.03690782	
152	35.9	0.1494	0.2934	-0.1441	0.0208	15.4	20.1	-4.6	21.4			

131	0	1.0000	1.0000	0.0000	0.0000	43.4	43.4	0.0	0.0	Temp =	102.9	312.4
131	8	0.7650	0.7734	-0.0084	0.0001	35.0	35.3	-0.3	0.1	R.H. =	11.62	
131	16	0.6850	0.6027	0.0823	0.0068	32.1	29.2	2.9	8.6	IMC (w.b.) =	40.4	67.9
131	24	0.4988	0.4711	0.0278	0.0008	25.5	24.5	1.0	0.9	EMC =	7.6	
131	32	0.3536	0.3688	-0.0152	0.0002	20.3	20.8	-0.6	0.3	k =	0.03359963	
131	40	0.3119	0.2892	0.0227	0.0005	18.8	18.0	0.8	0.6			
131	44.92	0.1588	0.2491	-0.0903	0.0081	13.3	16.6	-3.3	10.7			

97	0	1.0000	1.0000	0.0000	0.0000	43.4	43.4	0.0	0.0	Temp =	106.4	314.3
97	8	0.6969	0.7353	-0.0383	0.0015	33.1	34.4	-1.3	1.7	R.H. =	16.17	
97	16	0.5240	0.5456	-0.0216	0.0005	27.2	27.9	-0.7	0.5	IMC (w.b.) =	37.5	60.0
97	24	0.4075	0.4062	0.0012	0.0000	23.2	23.1	0.1	0.0	EMC =	9.3	
97	32	0.3666	0.3031	0.0635	0.0040	21.8	19.6	2.2	4.8	k =	0.04020866	
97	38.08	0.1598	0.2429	-0.0831	0.0069	14.8	17.6	-2.8	7.9			

76	0	1.0000	1.0000	0.0000	0.0000	55.4	55.4	0.0	0.0	Temp =	98.8	310.1
76	8.83	0.5904	0.7752	-0.1847	0.0341	38.5	46.1	-7.6	58.2	R.H. =	31.14	
76	16.83	0.6028	0.6196	-0.0169	0.0003	39.0	39.7	-0.7	0.5	IMC (w.b.) =	35.6	55.4
76	24.83	0.4945	0.4965	-0.0020	0.0000	34.5	34.6	-0.1	0.0	EMC =	14.1	
76	32.83	0.3977	0.3984	-0.0008	0.0000	30.5	30.6	0.0	0.0	k =	0.03023207	
76	40.83	0.4144	0.3201	0.0942	0.0089	31.2	27.3	3.9	15.1			
				SSE =	2.0329			SSE =	2219.8			
				MSE =	0.0135			MSE =	14.7			
				SEP =	0.1160			RMSE =	3.8			

Standard error of prediction calculation on the validation data using the Sharaf-Eldeen et al. (1980) model.

Code #	Time	Experimental MRAT	Predicted MRAT	Difference	Squared	Experimental M.C.	Predicted M.C.	Differenc	Squared			
135	0	1.0000	1.0000	0.0000	0.0000	42.9	42.9	0.0	0.0	Temp =	110	316.3
135	8	0.7028	0.8371	-0.1343	0.0180	34.0	38.1	-4.0	16.1	R.H. =	28.44	
135	16	0.4509	0.7041	-0.2532	0.0641	26.5	34.1	-7.6	57.1	IMC (w.b.) =	37.7	60.6
135	21.65	0.0724	0.6252	-0.5528	0.3056	15.3	31.7	-16.5	271.9	EMC =	13.1	
										k =	0.02600074	
141	0	1.0000	1.0000	0.0000	0.0000	40.0	40.0	0.0	0.0	Temp =	106.3	314.3
141	8	0.5848	0.8635	-0.2787	0.0777	27.2	35.8	-8.6	74.5	R.H. =	15.97	
141	16	0.5570	0.7481	-0.1911	0.0365	26.3	32.3	-5.9	35.2	IMC (w.b.) =	38.9	63.8
141	24	0.4303	0.6503	-0.2200	0.0484	22.4	29.2	-6.8	46.8	EMC =	9.2	
141	29.27	0.1829	0.5943	-0.4114	0.1693	14.8	27.5	-12.8	162.9	k =	0.0214086	
77	0	1.0000	1.0000	0.0000	0.0000	50.8	50.8	0.0	0.0	Temp =	97.9	309.6
77	11	0.8361	0.7637	0.0724	0.0052	44.8	42.1	2.7	7.2	R.H. =	29.97	
77	19	0.4577	0.6324	-0.1747	0.0305	30.8	37.2	-6.5	41.7	IMC (w.b.) =	33.7	50.8
77	27	0.4331	0.5275	-0.0944	0.0089	29.8	33.3	-3.5	12.1	EMC =	13.8	
77	35	0.1901	0.4434	-0.2533	0.0641	20.8	30.2	-9.4	87.6	k =	0.02886888	
68	0	1.0000	1.0000	0.0000	0.0000	60.0	60.0	0.0	0.0	Temp =	98.7	310.1
68	2.42	1.1837	0.9573	0.2263	0.0512	69.1	58.0	11.1	123.2	R.H. =	21.29	
68	10.42	1.0059	0.8304	0.1755	0.0308	60.3	51.7	8.6	74.0	IMC (w.b.) =	37.5	60.0
68	18.42	0.9348	0.7226	0.2122	0.0450	56.9	46.5	10.4	108.1	EMC =	11.0	
68	34.42	0.7218	0.5529	0.1689	0.0285	46.4	38.1	8.3	68.2	k =	0.02087458	

88	0	1.0000	1.0000	0.0000	0.0000	65.6	65.6	0.0	0.0	Temp =	98.6	310.0
88	12.7	0.8608	0.8322	0.0286	0.0008	57.7	56.1	1.6	2.6	R.H. =	14.65	
88	20.7	0.7000	0.7432	-0.0432	0.0019	48.6	51.0	-2.5	6.0	IMC (w.b.) =	39.6	65.6
88	28.7	0.6331	0.6652	-0.0321	0.0010	44.8	46.6	-1.8	3.3	EMC =	8.8	
88	36.7	0.4313	0.5968	-0.1655	0.0274	33.3	42.7	-9.4	88.5	k =	0.01692663	

154	0	1.0000	1.0000	0.0000	0.0000	39.0	39.0	0.0	0.0	Temp =	104.4	313.2
154	8	0.7739	0.8453	-0.0714	0.0051	34.3	34.6	-0.3	0.1	R.H. =	19.97	
154	16	0.6239	0.7176	-0.0937	0.0088	29.6	31.0	-1.3	1.8	IMC (w.b.) =	37.1	58.9
154	24	0.3795	0.6121	-0.2326	0.0541	22.0	28.0	-6.0	35.5	EMC =	10.6	
154	32	0.3114	0.5249	-0.2135	0.0456	19.9	25.5	-5.6	31.3	k =	0.02455814	
154	35.9	0.1679	0.4880	-0.3201	0.1024	15.4	24.4	-9.0	81.2			

98	0	1.0000	1.0000	0.0000	0.0000	30.1	30.1	0.0	0.0	Temp =	106.8	314.6
98	16	0.5008	0.6687	-0.1678	0.0282	20.7	23.8	-3.2	9.9	R.H. =	21.92	
98	24	0.2784	0.5526	-0.2743	0.0752	16.5	21.6	-5.2	26.6	IMC (w.b.) =	35.4	54.8
98	26.2	0.1972	0.5252	-0.3280	0.1076	14.9	21.1	-6.2	38.1	EMC =	11.2	
										k =	0.02996598	

157	0	1.0000	1.0000	0.0000	0.0000	48.3	48.3	0.0	0.0	Temp =	102.8	312.3
157	8	0.7172	0.8803	-0.1631	0.0266	37.0	43.5	-6.5	42.8	R.H. =	12.98	
157	16	0.4894	0.7768	-0.2874	0.0826	27.8	39.4	-11.5	132.8	IMC (w.b.) =	39.6	65.6
157	24	0.4570	0.6872	-0.2302	0.0530	26.5	35.8	-9.2	85.1	EMC =	8.2	
157	32	0.3008	0.6097	-0.3089	0.0954	20.3	32.7	-12.4	153.3	k =	0.01857564	
157	41.5	0.1510	0.5310	-0.3799	0.1443	14.3	29.5	-15.2	231.9			

94	0	1.0000	1.0000	0.0000	0.0000	16.1	16.1	0.0	0.0	Temp =	108	315.2
94	9.7	0.4430	0.7298	-0.2867	0.0822	12.8	14.5	-1.7	2.9	R.H. =	19.04	
										IMC (w.b.) =	32.7	48.6
										EMC =	10.2	
										k =	0.03840516	

133	0	1.0000	1.0000	0.0000	0.0000	50.0	50.0	0.0	0.0	Temp =	102.9	312.4
133	8	0.7647	0.8891	-0.1244	0.0155	40.0	45.3	-5.3	27.9	R.H. =	11.62	
133	16	0.5900	0.7921	-0.2021	0.0408	32.6	41.2	-8.6	73.6	IMC (w.b.) =	40.4	67.9
133	24	0.4981	0.7072	-0.2091	0.0437	28.7	37.6	-8.9	78.8	EMC =	7.6	
133	32	0.3445	0.6329	-0.2883	0.0831	22.2	34.5	-12.2	149.9	k =	0.01711422	
133	40	0.3214	0.5678	-0.2464	0.0607	21.2	31.7	-10.5	109.5			
133	44.92	0.1342	0.5318	-0.3976	0.1581	13.3	30.2	-16.9	285.0			

138	0	1.0000	1.0000	0.0000	0.0000	34.3	34.3	0.0	0.0	Temp =	107.3	314.8
138	8	0.6296	0.7695	-0.1399	0.0196	25.5	28.8	-3.3	11.0	R.H. =	19.75	
138	16	0.5006	0.5988	-0.0982	0.0096	22.4	24.7	-2.3	5.4	IMC (w.b.) =	32.5	48.1
138	24.7	0.0520	0.4628	-0.4108	0.1688	11.7	21.5	-9.7	95.0	EMC =	10.5	
										k =	0.03856316	

69	0	1.0000	1.0000	0.0000	0.0000	54.8	54.8	0.0	0.0	Temp =	97.5	309.4
69	11	0.7181	0.7937	-0.0756	0.0057	43.4	46.5	-3.1	9.3	R.H. =	32.08	
69	19	0.6723	0.6744	-0.0021	0.0000	41.6	41.7	-0.1	0.0	IMC (w.b.) =	35.4	54.8
69	27	0.3109	0.5760	-0.2652	0.0703	27.0	37.7	-10.7	115.0	EMC =	14.4	
69	35	0.4159	0.4946	-0.0787	0.0062	31.2	34.4	-3.2	10.1	k =	0.02467549	

128	0	1.0000	1.0000	0.0000	0.0000	42.1	42.1	0.0	0.0	Temp =	106.6	314.4
128	8	0.7646	0.8681	-0.1035	0.0107	34.5	37.9	-3.3	11.1	R.H. =	18.03	
128	16	0.5913	0.7558	-0.1645	0.0271	28.9	34.2	-5.3	28.1	IMC (w.b.) =	39.4	65.0
128	24	0.3220	0.6602	-0.3382	0.1144	20.3	31.2	-10.9	118.7	EMC =	9.9	
128	32	0.2928	0.5787	-0.2860	0.0818	19.3	28.5	-9.2	84.8	k =	0.02063241	
128	37.65	0.1405	0.5285	-0.3881	0.1506	14.4	26.9	-12.5	156.2			

104	0	1.0000	1.0000	0.0000	0.0000	39.5	39.5	0.0	0.0	Temp =	101.6	311.7
104	8	0.7328	0.8189	-0.0860	0.0074	31.7	34.2	-2.5	6.3	R.H. =	18.68	
104	16	0.5140	0.6747	-0.1607	0.0258	25.3	30.0	-4.7	22.1	IMC (w.b.) =	34.4	52.5
104	24	0.5069	0.5599	-0.0531	0.0028	25.1	26.6	-1.5	2.4	EMC =	10.2	
104	32	0.2677	0.4683	-0.2006	0.0402	18.0	23.9	-5.9	34.3	k =	0.02926769	
104	37.92	0.2074	0.4125	-0.2051	0.0421	16.3	22.3	-6.0	35.9			

146	0	1.0000	1.0000	0.0000	0.0000	36.7	36.7	0.0	0.0	Temp =	106.3	314.3
146	8	0.8806	0.8512	0.0294	0.0009	33.6	32.8	0.8	0.6	R.H. =	18.98	
146	16	0.8008	0.7275	0.0734	0.0054	31.4	29.5	1.9	3.8	IMC (w.b.) =	38.0	61.2
146	24	0.4378	0.6244	-0.1866	0.0348	21.8	26.8	-5.0	24.6	EMC =	10.2	
146	32	0.2958	0.5385	-0.2427	0.0589	18.0	24.5	-6.4	41.6	k =	0.02352242	
146	34.05	0.1165	0.5188	-0.4023	0.1619	13.3	24.0	-10.7	114.1			

101	0	1.0000	1.0000	0.0000	0.0000	23.2	23.2	0.0	0.0	Temp =	105.7	313.9
101	8.4	0.3958	0.8231	-0.4273	0.1826	14.3	20.6	-6.3	40.0	R.H. =	13.7	
										IMC (w.b.) =	36.3	56.9
										EMC =	8.4	
										k =	0.02714344	

115	0	1.0000	1.0000	0.0000	0.0000	28.5	28.5	0.0	0.0	Temp =	108.4	315.4
115	8	0.5876	0.7826	-0.1950	0.0380	21.0	24.6	-3.5	12.5	R.H. =	19.59	
115	24	0.1163	0.4943	-0.3780	0.1429	12.5	19.3	-6.8	46.8	IMC (w.b.) =	33.6	50.6
										EMC =	10.4	
										k =	0.0360236	

87	0	1.0000	1.0000	0.0000	0.0000	58.8	58.8	0.0	0.0	Temp =	97.5	309.4
87	5.6	0.8579	0.9030	-0.0451	0.0020	52.2	54.3	-2.1	4.4	R.H. =	24.79	
87	13.6	0.7803	0.7827	-0.0023	0.0000	48.6	48.7	-0.1	0.0	IMC (w.b.) =	37.1	58.9
87	29.6	0.4496	0.5940	-0.1444	0.0208	33.2	39.9	-6.7	45.2	EMC =	12.2	
87	37.6	0.2924	0.5205	-0.2282	0.0521	25.8	36.5	-10.6	112.9	k =	0.02118762	

71	0	1.0000	1.0000	0.0000	0.0000	52.5	52.5	0.0	0.0	Temp =	98.3	309.8
71	9.08	0.7443	0.8093	-0.0650	0.0042	41.8	44.6	-2.7	7.4	R.H. =	20.27	
71	25.08	0.5125	0.5674	-0.0549	0.0030	32.1	34.5	-2.3	5.3	IMC (w.b.) =	34.4	52.5
71	33.08	0.3785	0.4798	-0.1013	0.0103	26.5	30.8	-4.3	18.1	EMC =	10.7	
71	41.08	0.2378	0.4088	-0.1709	0.0292	20.7	27.8	-7.2	51.3	k =	0.0273302	

80	0	1.0000	1.0000	0.0000	0.0000	67.9	67.9	0.0	0.0	Temp =	97.8	309.6
80	15.08	0.6632	0.8216	-0.1583	0.0251	48.6	57.7	-9.1	82.2	R.H. =	19.73	
80	23.08	0.5916	0.7420	-0.1504	0.0226	44.5	53.1	-8.6	74.0	IMC (w.b.) =	40.4	67.9
80	31.08	0.5000	0.6714	-0.1713	0.0294	39.3	49.1	-9.8	96.1	EMC =	10.6	
80	39.08	0.4091	0.6086	-0.1995	0.0398	34.0	45.5	-11.4	130.3	k =	0.01526647	
80	47.08	0.3319	0.5528	-0.2210	0.0488	29.6	42.3	-12.6	159.8			

81	0	1.0000	1.0000	0.0000	0.0000	60.6	60.6	0.0	0.0	Temp =	97.2	309.2
81	13.75	0.6640	0.7935	-0.1294	0.0168	44.8	50.9	-6.1	37.2	R.H. =	29.12	
81	21.75	0.5202	0.6962	-0.1760	0.0310	38.0	46.3	-8.3	68.8	IMC (w.b.) =	37.7	60.6
81	29.75	0.4361	0.6128	-0.1768	0.0312	34.0	42.4	-8.3	69.4	EMC =	13.5	
81	37.75	0.2919	0.5413	-0.2494	0.0622	27.2	39.0	-11.7	138.0	k =	0.01976074	
81	53.75	0.2142	0.4270	-0.2128	0.0453	23.6	33.6	-10.0	100.6			

112	0	1.0000	1.0000	0.0000	0.0000	39.0	39.0	0.0	0.0	Temp =	110	316.3
112	8	0.9414	0.8040	0.1374	0.0189	37.5	33.9	3.6	13.0	R.H. =	28.27	
112	16	0.5106	0.6521	-0.1415	0.0200	26.3	29.9	-3.6	12.7	IMC (w.b.) =	35.3	54.5
112	24	0.3981	0.5342	-0.1361	0.0185	23.4	26.8	-3.4	11.4	EMC =	13.1	
112	26.55	0.3139	0.5025	-0.1886	0.0356	21.2	26.0	-4.7	22.3	k =	0.03234943	

132	0	1.0000	1.0000	0.0000	0.0000	43.7	43.7	0.0	0.0	Temp =	102.9	312.4
132	8	0.8839	0.8891	-0.0052	0.0000	39.5	39.7	-0.2	0.0	R.H. =	11.62	
132	16	0.7728	0.7921	-0.0193	0.0004	35.5	36.2	-0.7	0.5	IMC (w.b.) =	40.4	67.9
132	24	0.5728	0.7072	-0.1344	0.0181	28.3	33.1	-4.9	23.7	EMC =	7.6	
132	32	0.4102	0.6329	-0.2227	0.0496	22.4	30.5	-8.1	64.9	k =	0.01711422	
132	40	0.3198	0.5678	-0.2480	0.0615	19.1	28.1	-9.0	80.5			
132	44.92	0.1577	0.5318	-0.3742	0.1400	13.3	26.8	-13.5	183.0			

91	0	1.0000	1.0000	0.0000	0.0000	40.5	40.5	0.0	0.0	Temp =	110.1	316.4
91	8	0.5150	0.7948	-0.2797	0.0783	27.2	34.9	-7.7	59.5	R.H. =	28.15	
91	26.5	0.0881	0.4836	-0.3956	0.1565	15.4	26.3	-10.9	119.2	IMC (w.b.) =	34.8	53.4
										EMC =	13.0	
										k =	0.03371778	

123	0	1.0000	1.0000	0.0000	0.0000	24.0	24.0	0.0	0.0	Temp =	106.4	314.3
123	8	1.0667	0.7914	0.2752	0.0758	25.1	20.8	4.3	18.3	R.H. =	13.86	
123	16	0.6035	0.6319	-0.0284	0.0008	17.9	18.3	-0.4	0.2	IMC (w.b.) =	33.7	50.8
123	24	0.7706	0.5096	0.2610	0.0681	20.5	16.4	4.1	16.6	EMC =	8.5	
123	26	0.2381	0.4838	-0.2457	0.0604	12.2	16.0	-3.8	14.4	k =	0.03435068	

137	0	1.0000	1.0000	0.0000	0.0000	24.6	24.6	0.0	0.0	Temp =	107.3	314.8
137	8	0.8141	0.7695	0.0446	0.0020	22.0	21.4	0.6	0.4	R.H. =	19.75	
137	16	0.4706	0.5988	-0.1282	0.0164	17.2	19.0	-1.8	3.2	IMC (w.b.) =	32.5	48.1
137	24.7	0.0874	0.4628	-0.3753	0.1409	11.7	17.0	-5.3	27.9	EMC =	10.5	
										k =	0.03856316	

152	0	1.0000	1.0000	0.0000	0.0000	42.9	42.9	0.0	0.0	Temp =	104.4	313.2
152	8	0.7407	0.8453	-0.1046	0.0109	34.5	37.9	-3.4	11.4	R.H. =	19.97	
152	16	0.6311	0.7176	-0.0865	0.0075	31.0	33.8	-2.8	7.7	IMC (w.b.) =	37.1	58.9
152	24	0.4155	0.6121	-0.1966	0.0387	24.0	30.4	-6.3	40.1	EMC =	10.6	
152	32	0.3472	0.5249	-0.1777	0.0316	21.8	27.5	-5.7	32.7	k =	0.02455814	
152	35.9	0.1494	0.4880	-0.3386	0.1146	15.4	26.3	-10.9	119.2			

131	0	1.0000	1.0000	0.0000	0.0000	43.4	43.4	0.0	0.0	Temp =	102.9	312.4
131	8	0.7650	0.8891	-0.1241	0.0154	35.0	39.5	-4.5	19.8	R.H. =	11.62	
131	16	0.6850	0.7921	-0.1071	0.0115	32.1	36.0	-3.8	14.8	IMC (w.b.) =	40.4	67.9
131	24	0.4988	0.7072	-0.2083	0.0434	25.5	33.0	-7.5	55.9	EMC =	7.6	
131	32	0.3536	0.6329	-0.2793	0.0780	20.3	30.3	-10.0	100.5	k =	0.01711422	
131	40	0.3119	0.5678	-0.2559	0.0655	18.8	28.0	-9.2	84.5			
131	44.92	0.1588	0.5318	-0.3730	0.1391	13.3	26.7	-13.4	179.2			
97	0	1.0000	1.0000	0.0000	0.0000	43.4	43.4	0.0	0.0	Temp =	106.4	314.3
97	8	0.6969	0.8449	-0.1480	0.0219	33.1	38.1	-5.0	25.5	R.H. =	16.17	
97	16	0.5240	0.7170	-0.1931	0.0373	27.2	33.8	-6.6	43.3	IMC (w.b.) =	37.5	60.0
97	24	0.4075	0.6114	-0.2039	0.0416	23.2	30.2	-6.9	48.3	EMC =	9.3	
97	32	0.3666	0.5241	-0.1574	0.0248	21.8	27.2	-5.4	28.7	k =	0.02461943	
97	38.08	0.1598	0.4680	-0.3081	0.0949	14.8	25.3	-10.5	110.3			
76	0	1.0000	1.0000	0.0000	0.0000	55.4	55.4	0.0	0.0	Temp =	98.8	310.1
76	8.83	0.5904	0.8294	-0.2389	0.0571	38.5	48.4	-9.9	97.4	R.H. =	31.14	
76	16.83	0.6028	0.7033	-0.1005	0.0101	39.0	43.2	-4.2	17.3	IMC (w.b.) =	35.6	55.4
76	24.83	0.4945	0.5994	-0.1049	0.0110	34.5	38.9	-4.3	18.8	EMC =	14.1	
76	32.83	0.3977	0.5135	-0.1159	0.0134	30.5	35.3	-4.8	22.9	k =	0.02480451	
76	40.83	0.4144	0.4426	-0.0283	0.0008	31.2	32.4	-1.2	1.4			
				SSE =	6.0412			SSE =	6867.3			
				MSE =	0.0400			MSE =	45.5			
				SEP =	0.2000			RMSE =	6.7			

APPENDIX B

FORTRAN Code

```
program MOISTURECONTENT

!********Ear Corn Equilibrium Moisture Content Calculator******
!Developed by Nick Friant 11/19/01

!This program was developed to calculate the equilibrium moisture
!content of ear corn given the drying air temperature and relative
!humidity.

    Write(*,*)'******Equilibrium Moisture Content Calculator******'
    WRITE(*,*)
69  WRITE(*,*)
    WRITE(*,*)'ENTER THE DRYING AIR TEMPERATURE (DEG. F)'
    READ (*,*) TF
    WRITE(*,*)
    WRITE(*,*)'ENTER THE DRYING AIR RELATIVE HUMIDITY (%)'
    READ (*,*) RH
    WRITE(*,*)
    RH=RH/100
    TK=((5.0/9.0)*(TF-32))+273
    EMC=5.69*((-(LOG(1-RH))/TK))**0.55
    EMC=EMC*100
    WBEMC=(100*EMC)/(100+EMC)
    WRITE(*,*)
    WRITE(*,*)'THE EQUILIBRIUM MOISTURE CONTENT IS (%, d.b.)', EMC
    WRITE(*,*)
    WRITE(*,*)'THE EQUILIBRIUM MOISTURE CONTENT IS (%, W.B.)', WBEMC
    WRITE(*,*)'RUN AGAIN? (Y/N)'
    READ 900, REPLY
    IF (REPLY.EQ.'Y'.OR.REPLY.EQ.'y') GOTO 69
900 FORMAT (A)
    END
```

```
program emc
!********** Equilibrium Moisture Content of Ear Corn **********

!Developed spring 2000 by Nick Friant revised 10/18/01

!This program will determine the equilbrium moisture content (EMC)
!of ear corn based on varying the drying air temperature or the
!drying air relative humidity.  This program provides the data to
!develop a curve for the EMC when one of the two variables is held
!constant and the other is varied by the given step size.

    WRITE(*,*)
    WRITE(*,*)'*******EMC CALCULATOR FOR VARYING INPUTS*******'
    WRITE(*,*)
96  WRITE(*,*)'ENTER THE DRYING-AIR TEMPERATURE (DEG. F)'
    READ (*,*) T
    WRITE(*,*)
    WRITE(*,*)'ENTER THE DRYING-AIR RELATIVE HUMIDITY (%)'
    READ (*,*)RH
    WRITE(*,*)
    WRITE(*,*)'ENTER THE PARAMETER TO BE VARIED (T/RH)'
    READ 900, REPLY
    WRITE(*,*)
    WRITE(*,*) 'ENTER THE STEP SIZE (DECIMAL OF PERCENTAGE FOR RH)'
    READ (*,*)X
    WRITE(*,*)
    T=(5.0/9.0)*(T-32)+273.1
    RH=RH/100
    IF(REPLY.EQ.'T'.OR.REPLY.EQ.'t') THEN
    GOTO 38
    ELSE
    GOTO 40
    ENDIF
38  DO 69, T=273,T,X
    EMCDB=5.69*((-(LOG(1-RH))/T))**0.55
    EMCWB=(100*(EMCDB*100))/(100+(EMCDB*100))
    WRITE(*,*)'THE EMC IS (%,W.B.)', EMCWB
    WRITE(*,*)'AT (KELVIN)         ', T
    PAUSE
69  CONTINUE
40  DO 41, RH=0,RH,X
    EMCDB=5.69*((-(LOG(1-RH))/T))**0.55
    EMCWB=(100*(EMCDB*100))/(100+(EMCDB*100))
    WRITE(*,*)'THE EMC IS (%,W.B.)', EMCWB
    WRITE(*,*)'AT (KELVIN)         ', T
    PAUSE
41  CONTINUE
    WRITE(*,*)
    WRITE(*,*) 'RUN AGAIN? (Y/N)'
    READ 900, REPLY
    IF(REPLY.EQ.'Y'.OR.REPLY.EQ.'y') GOTO 96
900 FORMAT (A)
    END
```

```
PROGRAM DRYPARAM
!**********Drying Parameter, k, Calculator**********
!Revised 2/12/02 By Nick Friant

!This program uses the temperature and initial moisture content to
!calculate the drying parameter k.

REAL k, MC
WRITE(*,*)
WRITE(*,*)'**********DRYING PARAMTER k CALCULATOR**********'
WRITE(*,*)
WRITE(*,*)'ENTER THE TEMPERATURE (DEGREES F)'
READ (*,*) Y
WRITE(*,*)
WRITE(*,*)'ENTER THE INITIAL MOISTURE CONTENT (%, W.B.)'
READ (*,*) Z
WRITE(*,*)
A=-28.65590333
B=7946.8012548
C=0.2743851787
D=-86.0032229
T=((5.0/9.0)*(Y-32.0))+273
MC=((100*Z)/(100-Z))/100
k=EXP(A+(C*T+D)*MC+(B/T))
WRITE(*,*)'DRYING PARAMTER k=', k
END
```

```
      program AIRPROPS
!     ***************** Air Properties ***************
!     Development started 4/25/01 by Nick Friant
!     This program will calculate the properties of air.
!     It will initially be used to determine the density of air
!     at different temperatures and relative humidities.
!     Other properties may be added.
!     Calculation of relative humidity given wet-bulb and dry-bulb
!     temperatures added 6/19/01.  Code follows SI code developed by
!     Bakker et al. Advances in Cereal Chemistry and Technology
!     Volume II, 1978.  MSU TS2120.A3, pp.1-90.

      WRITE(*,*)
      WRITE(*,*)'*************** AIR PROPERTIES ***************'
      WRITE(*,*)
520   WRITE(*,*)
      WRITE(*,*)'WHAT TWO VALUES ARE KNOWN?'
      WRITE(*,*)
      WRITE(*,*)'1 FOR DRY-BULB AND WET-BULB TEMPERATURE'
      WRITE(*,*)'2 FOR DRY-BULB TEMPERATURE AND RELATIVE HUMIDITY'
      WRITE(*,*)
      READ 900, REPLY
      IF(REPLY.EQ.'1') THEN
      GOTO 52
      ELSE
      GOTO 96
      ENDIF
!     THIS PORTION OF THE PROGRAM CALCULATES THE
!     RELATIVE HUMIDTY OF AIR GIVEN THE DRY- AND
!     WET-BULB TEMPERATURES.  EQNS WERE DEVELOPED FROM
!     ASAE STANDARDS, L.E.LEREW AND BAKKER-ARKEMA ET AL.
52    WRITE(*,*)
      WRITE(*,*)'ENTER THE DRY-BULB TEMPERATURE (DEG F)'
      READ(*,*) TDB
      WRITE(*,*)
      WRITE(*,*)'ENTER THE WET-BULB TEMPERATURE (DEG F)'
      READ(*,*) TWB
      WRITE(*,*)
!     CONVERT DEG F TO KELVIN
      TDBK= (5.0/9.0)*(TDB-32.0)+273.16
      TWBK= (5.0/9.0)*(TWB-32.0)+273.16
!     CALCULATE H"fg BASED ON EQN IN ASAE STANDARDS USING WET-BULB TEMP
      HFG=2502535.259-2385.76424*(TWBK-273.16)
!     CALCULATE SATURATION VAPOR PRESSURE USING WET-BULB, BASED ON
!     PSYCHROMETRIC PROGRAM DEV. BY BAKKER-ARKEMA ET AL.
!     EQN FROM ASAE STANDARDS
      DATA R, A, B, C, D, E, F, G/.2210584739E08, -.274055258361E05,&
      .9754129373E02, -.1462440044, .1255753189E-03, -.4850171032E-07,&
      .43490287800E01, .3938107141E-02/
      PVSWB=R*EXP((A+TWBK*(B+TWBK*(C+TWBK*(D+TWBK*E))))&
      /(TWBK*(F-G*TWBK)))
!     CALCUALTE SATURATION VAPOR PRESSURE USING DRY-BULB,
!     SAME REF. AS ABOVE.
!     NECESSARY TO CALCULATE THE RELATIVE HUMIDITY
```

```
      PVSDB=R*EXP((A+TDBK*(B+TDBK*(C+TDBK*(D+TDBK*E))))&
      /(TDBK*(F-G*TDBK)))
!     CALCULATE VAPOR PRESSURE USING DRY- AND WET-BULB.
!     SAME REF. AS ABOVE.
!     PATM=101325 Pa
      X=PVSWB
      Y=0.62194*HFG*101325
      Z=1006.9254*(X-101325)*(TWBK-TDBK)
      PV=(X*Y-Z*101325)/(Y+0.15577*Z)
!     CALCULATE RELATIVE HUMIDY FROM ASAE STANDARDS
      RH=(PV/PVSDB)*100
!     CALCULATE AIR HUMIDITY RATIO BASED ON ASAE STANDARDS
      W=(.622*PV)/(101325-PV)
      WRITE(*,*)
      WRITE(*,*)'LATENT HEAT OF VAPORIZATION, H"fg (J/KG)', HFG
      WRITE(*,*)'WET-BULB SATURATION VAPOR PRESSURE (Pa) ', PVSWB
      WRITE(*,*)'DRY-BULB SATURATION VAPOR PRESSURE (Pa) ', PVSDB
      WRITE(*,*)'VAPOR PRESSURE (Pa)           ', PV
      WRITE(*,*)'RELATIVE HUMIDITY (%)             ', RH
      WRITE(*,*)'HUMIDITY RATIO                                ', W
      PAUSE
      GOTO 722


!     THIS PORTION OF THE PROGRAM CALCULATES THE DENTSITY OF AIR GIVEN
!     THE TEMPERATURE AND RELATIVE HUMIDITY.
!     EQNS ARE ADAPTED FROM ASAE
!     STANDARDS, L.E.LEREW (1972) AND BROOKER et al. (1992)
!     'DRYING & STORAGE OF GRAINS AND OILSEEDS'
96    WRITE(*,*)
      WRITE(*,*)'ENTER THE TEMPERATURE (DEG F)'
      READ(*,*) TF
      WRITE(*,*)
      WRITE(*,*) 'ENTER THE RELETIVE HUMIDITY (%)'
      READ(*,*) RH
      WRITE(*,*)
      WRITE(*,*)
!     CONVERT TEMPERATURE FROM DEG F TO KELVIN
      TK=(5.0/9.0)*(TF-32.0)+273.16
!     CONVERT RH TO DECIMAL
      RH=RH/100
!     CALCULATE SATURATION PRESSURE BASED ON
!     ASAE STANDARDS AND L.E.LEREW (1972)
!     USES SAME R, A, B, C, D, E, F, G, AS ABOVE.
      PS=(R*EXP((A+TK*(B+TK*(C+TK*(D+TK*E))))/(TK*(F-G*TK))))/1000
!     CALCULATE AIR HUMIDITY RATIO BASED ON ASAE STANDARDS
      W=.622*(RH*PS/(101.325-RH*PS))
!     CALCULATE SPECIFIC VOLUME OF AIR BASED ON SASE STANDARDS
      V=((287.09*TK)/(101.325-(RH*PS)))/1000
!     CALCULATE AIR DENSITY
      RHOA=1/V
      WRITE(*,*) 'TEMPERATURE (K)                ', TK
      WRITE(*,*) 'SATURATION PRESSURE (KPA)      ', PS
      WRITE(*,*) 'HUMIDITY RATIO (KG/KG)         ', W
```

```
      WRITE(*,*) 'SPECIFIC VOLUME (M^3/KG)      ', V
      WRITE(*,*) 'AIR DENSITY (KG/M^3)          ', RHOA
      PAUSE
69    CONTINUE
      WRITE(*,*)
722   WRITE(*,*) 'ENTER NEW DATA? Y/N'
      READ 900, REPLY
      IF(REPLY.EQ.'Y'.OR.REPLY.EQ.'y') GOTO 520
900   FORMAT(A)
      END
```

```
program dryr8

!**********Thin-layer Drying of Ear Corn**********
!Developed by Nicholas R. Friant 2/27/02 Revised 3/25/02
!This is a main program with subfuctions to determine the average
!moisture content of ear corn at any time during thin-layer drying.
!Ear M.C. is entered in % wet basis, converted to dry basis for
!calculation and converted back to wet basis for output.

!1.The main program of dryr8 give the average moisture content of
!ear corn at any given time during thin-layer drying.

    REAL MC, MCWB
    REAL MAVG, MRAT
    REAL K, N
    WRITE(*,*)
    WRITE(*,*)'*******THIN-LAYER EAR-CORN MOISTURE CALCULATOR*******'
96  WRITE(*,*)
    WRITE(*,*)'ENTER THE DRYING TIME (HOURS)'
    READ (*,*)TI
    WRITE(*,*)
    WRITE(*,*)'ENTER THE TIME STEP (HOURS)'
    READ (*,*)X
    WRITE(*,*)
    WRITE(*,*)'ENTER THE INITIAL MOISTURE CONTENT (%, W.B.)'
    READ (*,*)MCWB
    WRITE(*,*)
    WRITE(*,*)'ENTER THE DRYING-AIR RELATIVE HUMIDITY (%)'
    READ (*,*)RH
    WRITE(*,*)
    WRITE(*,*)'ENTER THE DRYING-AIR TEMPERATURE (DEG. F)'
    READ (*,*)TF
    WRITE(*,*)

!Constants for Friant's Equation
    A=-28.65590333
    B=7946.8012548
    C=0.2743851787
    D=-86.00322229
    N=0.9915435211

!Conversion of input to the correct form
    RH=RH/100
    MC=(100*MCWB)/(100-MCWB)
    TC=(TF-32)*(5.0/9.0)
    TK=TC+273

!Calculation of the equilibrium moisture content
    EMC=5.69*((-(LOG(1-RH))/TK))**0.55
    EMC=EMC*100
    EMCWB=(100*EMC)/(100+EMC)

!Claculation of the drying parameter K
    K=EXP(A+(C*TK+D)*(MC/100)+(B/TK))
```

```
!Calculation of the average moisture content at any given time
    DO 69, TI=0,TI,X
    MAVG=(EXP(-K*(TI**N))*((MC/100)-(EMC/100))+(EMC/100))*100
    WBMAVG=(100*MAVG)/(100+MAVG)
    MRAT=(MAVG-EMC)/(MC-EMC)
    WRITE(*,*)
    WRITE(*,*)'THE INITIAL EAR MOISTURE CONTENT IS          ',MC
    WRITE(*,*)'THE DRYING PARAMTER K IS                     ',K
    WRITE(*,*)'THE EMC DRY BASIS IS                     ',EMC
    WRITE(*,*)'THE EMC WET BASIS IS                     ',EMCWB
    WRITE(*,*)'THE AVERAGE EAR MOISTURE CONTENT DRY BASIS IS',MAVG
    WRITE(*,*)'THE AVERAGE EAR MOISTURE CONTENT WET BASIS IS',WBMAVG
    WRITE(*,*)'THE MOISTURE RATIO IS                        ',MRAT
    PAUSE
69  CONTINUE
    WRITE(*,*)
    WRITE(*,*)'RUN AGAIN WITH NEW INPUTS? (Y/N)'
    READ 900, REPLY
    IF(REPLY.EQ.'Y'.OR.REPLY.EQ.'y') GOTO 96
900 FORMAT (A)

    END

!Glossary
!A,B,C,D,N -> Constants in the Friant Equation
!TI ->Total drying time in hours
!X ->Time step taken during the drying cycle
!MCWB ->Inital moisture content, percent wet basis
!RH ->Drying air relative humidity, percent
!TF ->Drying air temperature, degrees Fahrenheit
!MC ->Initial ear moisture content converted to dry basis
!TC ->Drying air temperature converted to degrees Celcius
!TK ->Drying air temperature converted to Kelvin
!EMC ->Equilibrium moisture content, determined as a decimal,
!      converted to a percent for use in Friant Equation
!EMCWB ->Equilibrium moisture content converted to wet basis
!        for ease of understanding output
!K ->Drying paramter
!MAVG ->Average ear moisture content, dry basis,of ear corn at any ti
me
!WBMAVG -> Average ear moisture content, wet basis, of ear corn
!          at any time
!MRAT ->Moisture ratio at any time during the drying cycle
```

APPENDIX C

Equipment Specifications

Equipment Specifications

PQ-100 Single Kernel Moisture Meter

(Seedburo Equipment Company, Chicago, Illinois)

- Application: Corn
- Measuring principal: DC resistance
- Display: LED display
- Temperature sensor: Thermistor
- Data output: Printer hardcopy
- Number of kernels settable: 11 to 599 kernels (1 kernel increments)
- Measuring range: 9 to 40% (wet basis) at 20° C
- Operating temperature: 5°C to 40°C
- Measuring speed: 100 kernels per minute
- Power supply: AC 120 Volts, 60 Hz
- Dimensions: Main body → 240 x 330 x 380 mm,
  Controller → 120 x 245 x 55mm
- Weight: Main body → 18kg
  Controller → 650g

Yamato DX-400 Gravity Drying Oven

(Yamato Scientific American, Incorporated, Orangeburg, New Jersey)

- Operating temperature range: 40°C to 300°C
- Temperature adjustment accuracy: ±1.0°C (at 260°C)
- Temperature distribution accuracy: ±8° C at 300°C
- Time to reach maximum temperature: 60 min.
- Temperature control system: PID controlled by microcomputer

- Temperature setting system: Digital setting system by ▲ and ▼ keys
- Operation mode: Fixed temperature operation
- Additional functions: temperature preset function
- Heater: Iron – chrome wire heater
- System capacity: 1.36kW
- Control of heater circuit: TRIAC zero cross system
- Sensor: Platinum resistance bulb (Pt 100Ω)
- Interior lining: Stainless Steel SUS304
- Safety systems: Self-diagnostic functions, circuit breaker, alarm buzzer
- Internal dimensions: 17.7 x 16.1 x 15.7" (449.6 x 408.9 x 398.8 mm)
- External dimensions: 21.6 x 21.6 x 28.7" (548.6 x 548.6 x 729 mm)
- Internal capacity: 2.6 ft^3 (0.7362 m^3)
- Shelf/ Shelf brackets: 2 sets
- Electrical capacity: 115VAC, 2A
- Weight: 84 lbs. (38.1 kg)

Grain Analysis Computer, Model GAC2000
(DICKEY-John Corporation, Auburn, Illinois)

- Supply Voltage: 85VAC to 264VAC, 48-62Hz at 0.4A maximum
- Operating temperature: 5°C to 45°C (41°F to 113°F)
- Grain temperature limits: 0°C to 50°C (32°F to 122°F)
- Weight: 11.8 kg (26lbs.)