2004 MAFMA Final Report

Project Title	**Site-specific drying and conditioning of identity-preserved quality food grains**
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1. Objective Summary

During 2004 and 2005, we accomplished what we had stated in Objective 1 (*To determine the adsorption and desorption equilibrium moisture content (EMC) relationship for corn with laboratory experiments, incorporate them into our PHAST-FDM model, and quantify the hysteresis effect on drying simulation models*), Objective 3 (*Based on preliminary experiments from the fall 2003, the results from the laboratory experiments (Objectives 1 and 2) and the results of the drying experiments, the new self adapting variable heat (SAVH) strategy will be further refined*), and Objective 4 (*To evaluate an improved EMC controlled SAVH in-bin low temperature drying and conditioning prototype system at four Indiana locations during the 2004-05 drying and storage season, and quantify its benefits on quality and purity of IP food corn in collaboration with The GSI Group (Assumption, Il) and Frito-Lay (Sidney, Il)*). Based on the progress and results of our research we also determined that the proposed research in Objective 2 *(To conduct a series of thin-layer drying experiments in the laboratory at low temperature drying conditions, determine the appropriate set of constants for low temperature drying models, and incorporate them into our PHAST-FDM model)* was not necessary because the EMC-based approach proved to be sufficiently accurate for the model-based controller.

Three different corn types (yellow dent, waxy and white) were used in a set of desorption and adsorption equilibrium moisture content (EMC) experiments. The ranges of temperature and moisture content (MC) for the tests were 0 to 25ºC and 12 to 20%. The main conclusion was that the three corn types investigated had different adsorption and desorption EMC relationships.

These corn type specific relationships were incorporated into a new model-based fan and burner control strategy for the in-bin drying and conditioning of corn. This Self-Adapting Variable Heat (SAVH) strategy incorporated the Thompson equilibrium drying model to predict MC changes in different layers of the grain mass. The drying model allowed the SAVH control strategy to successfully identify wet or dry weather conditions and target a uniform final MC for the entire grain mass.

This SAVH control strategy was successfully implemented in three field experiments during the 2004 drying season. The Post-Harvest Aeration and Storage Simulation Tool – Finite Difference Method (PHAST-FDM) software was further refined and validated by comparing the observed MC values for four natural air / low temperature (NA/LT) in-bin drying experiments with the predicted MC values.

On the basis of a 40-year analysis of weather data with respect to the performance of NA/LT in-bin drying systems, the Midwestern Corn Belt was divided into four regions. PHASTFDM was used to study the performance of four NA/LT in-bin drying strategies for drying 20% initial MC corn in 13 locations within these regions. The simulation results showed that the SAVH strategy outperformed the other strategies on the basis of drying costs (from 1.1 to 9.6 $/t lower drying cost), drying time, and relatively little overdrying of the grain bottom layer. The drying cost for the yellow dent corn type was always the lowest, followed by the white and then by the waxy corn types.

The fine material distribution in the grain mass and the air velocity through the core and periphery locations in the bin were quantified for 15 NA/LT in-bin drying field tests. The best management practices of leveling the grain peak after filling the bin and coring the grain mass were implemented, and the improvement on the airflow distribution was quantified. Simulation results showed that operators of NA/LT in-bin drying systems could reduce drying costs from 25 to 33% by leveling the grain peak after loading the bin. An additional savings of 18 to 22% could be achieved by installing effective grain (and fine material) distributors or by coring the grain mass.

2. Objective Accomplishments

Objective 1 (*To determine the adsorption and desorption equilibrium moisture content (EMC) relationship for corn with laboratory experiments, incorporate them into our PHAST-FDM model, and quantify the hysteresis effect on drying simulation models*).

The Modified Chung-Pfost equation is one of the most accepted equilibrium moisture content (EMC) models for corn. In the past, considerable effort has been made to find a universal set of parameters to accurately represent the EMC for most of the commercially available corn hybrids. Unfortunately, such a universal set of parameters has not yet been found.

In this study, three different corn types (yellow dent, waxy and white) harvested during the 2003 fall harvest season were used to run a set of desorption and adsorption EMC/ERH experiments. The range of temperature and moisture content (MC) for the tests were designed to cover the typical operating conditions for natural air / low temperature in-bin drying systems in the Midwest during the fall (0 to 25ºC and 12 to 20% for temperature and MC, respectively). A statistical procedure was used to determine the best adsorption and desorption parameters for the Modified Chung-Pfost equation for each corn type. A second adsorption and desorption EMC/ERH experiment was carried out with samples of yellow dent and white corn harvested during the 2004 drying season. The Modified Chung-Pfost equation using the 2003 set of parameters was validated with the 2004 EMC/ERH data.

The main conclusions of this study were that the different corn types investigated had different EMC/ERH relationships, the adsorption and desorption relationships were different for each corn type, and the prediction of EMC/ERH values using the current ASAE Standard set of parameters was significantly different compared to the white and waxy corn EMC/ERH data reported in this research.

Objective 2 (*To conduct a series of thin-layer drying experiments in the laboratory at low temperature drying conditions, determine the appropriate set of constants for low temperature drying models, and incorporate them into our PHAST-FDM model*).

After a further evaluation of the existing low temperature drying models it was concluded that the Thompson Equilibrium drying model had advantages over the Thin Layer drying model. The Thompson Equilibrium model is simple, easy to implement and more reliable than the Thin Layer model for predicting the series of drying and rewetting cycles occurring during natural air/low temperature in-bin drying processes. The key component of the Thompson Equilibrium drying model is to have a reliable EMC relationship. Under Objective 1 we were able to obtain a reliable set of adsorption and desorption EMC relationships for three different corn types (yellow dent, white and waxy). Thus, the Thompson Equilibrium drying model was chosen to predict MC changes during the in-bin drying and conditioning of corn. As a result, the thin layer experiments were no longer required to achieve the main goal of this research, which was to develop a new model-based fan and burner control strategy for the in-bin drying and conditioning of corn.

Objective 3 (*Based on preliminary experiments from the fall 2003, the results from the laboratory experiments (Objectives 1 and 2) and the results of the drying experiments, the new self adapting variable heat (SAVH) strategy will be further refined*).

A new model-based fan and burner control strategy for the in-bin drying and conditioning of corn was developed. This Self-Adapting Variable Heat (SAVH) fan and burner control strategy incorporated the Thompson equilibrium drying model to predict MC changes in different layers of the grain mass. The drying model allowed the SAVH control strategy to successfully identify wet or dry weather conditions and respond to it accurately. The SAVH strategy was incorporated into the PHAST-FDM simulation model and evaluated for different drying conditions. During a dry fall, the SAVH control strategy avoided the overdrying of corn by selecting the best fan operating hours and seldom using supplemental heat. During a wet fall, the SAVH control strategy successfully dried corn by using supplemental heat more aggressively. During both dry and wet fall periods, the SAVH control strategy was capable of targeting a specific final MC close to the set point of 15% (14.5 and 14.9% for the dry and wet fall, respectively).

Objective 4 (*To evaluate an improved EMC controlled SAVH in-bin low temperature drying and conditioning prototype system at four Indiana locations during the 2004-05 drying and storage season, and quantify its benefits on quality and purity of IP food corn in collaboration with The GSI Group (Assumption, Il) and Frito-Lay (Sidney, Il)*).

A new model-based SAVH fan and burner control strategy for the in-bin drying and conditioning of corn was successfully implemented in three field experiments during the 2004 drying season. These experiments were carried out in three different locations throughout Indiana, in bins with different capacities (from 57 to 431 tonnes) and with two different corn types (yellow dent and white corn). One continuous natural air (CNA) experiment was also carried out drying yellow dent corn in a 57-tonne bin. The SAVH control strategy was able to successfully dry wet corn to a final MC close to 15%, with a relatively uniform final MC in the entire grain mass. Compared to the CNA strategy, the SAVH control strategy successfully avoided the overdrying of the grain under the same weather conditions.

The PHAST-FDM model was enhanced with the incorporation of three corn-type specific EMC relationships, the adsorption and desorption EMC curves for the three corn types, and the differential airflow rate between center versus the side of the bin. The PHAST-FDM model was validated by comparing the observed MC values for the four experiments implemented during the 2004 drying season with the MC values predicted by the model. The PHAST-FDM model was able to predict MC distribution within the bin with a low error (standard error ranging from 0.44 to 0.70%).

The Midwestern Corn Belt was divided into four different regions according to the likelihood for successful natural air/low temperature (NA/LT) in-bin drying. The PHAST-FDM simulation model was used to study the in-bin drying of corn in each one of the previously identified regions using 40 years of historical weather data (1961-2000). The performance of four NA/LT in-bin drying strategies for drying 20% initial MC corn were evaluated. These strategies were CNA, continuous constant heat (CCH), variable heat (VH) and the newly developed SAVH strategy. The results showed that the

SAVH strategy outperformed the other strategies on the basis of the maximum expected drying cost, occurring with a probability of 90% (Drying Cost*), the longest expected drying time, occurring with a probability of 90% (Drying Time*), and overdrying of the grain bottom layer.

The limits for the operation of the SAVH strategy for drying corn (from 18 to 24% initial MC) at different harvest dates (from September 1 to December 1) were determined for each one of these regions on the basis of the maximum expected dry matter loss of the top grain layer, occurring with a probability of 90% (DML Max*), and the Drying Cost*. The results showed that for the coldest region the DML Max* was not a limitation for drying 24% wet corn (DML Max* less than 0.5%). Limitations in the harvest dates were observed for initial MCs of 24 and 22% corn in the warmer regions (DML Max* greater than 0.5% for early harvest dates). The Drying Cost* increased with the initial MC of corn and with later harvest dates. Across all the regions and harvest dates, the Drying Cost* for 18% corn ranged from 3.4 to 8.4 $/t, and for 24% corn it ranged from 7.4 to 12.0 $/t.

3. Unexpected findings, if any

Two additional objectives were proposed to further explore the performance of the SAVH strategy for in-bin drying and conditioning of different corn types, which resulted in some unexpected findings:

Objective 5 (*To compare the drying characteristics of different corn types (yellow dent, white and waxy) in different locations in the Midwestern Corn Belt*).

The adsorption and desorption EMC parameters for the yellow dent, white and waxy corn types were incorporated into the PHAST-FDM model. The performance of the SAVH strategy for drying different corn types was evaluated for different locations in the Midwest on the basis of Drying Cost*. The Drying Cost* (maximum expected drying cost occurring with a probability of 90%) for the yellow dent corn type was compared to the Drying Cost* for the white and waxy corn types for four different locations. It was found that the Drying Cost* for the yellow dent corn type was the lowest for all locations, followed by the white corn type and last by the waxy corn type. The difference in the Drying Cost* was more significant in the northern regions (North Platte, Nebraska), where the Drying Cost* for the white corn type was 17.0% more expensive than the Drying Cost* for the yellow dent corn type, while the waxy corn type was 52.2% more expensive. The higher Drying Cost* predicted for the white and waxy corn types was related to the longer drying time required for these two corn types when compared to the drying time required for the yellow dent corn type. The predicted difference in Drying Cost* among the three corn hybrids was greater than expected and had never been documented previously.

Objective 6 (*To quantify the non-uniform distribution of the fine material and the airflow rate in several NA/LT in-bin drying systems, operated under typical on-farm conditions, and to study, using the aid of simulation tools, the potential drying cost savings during the NA/LT in-bin drying of corn resulting from implementing best management practices to improve the distribution of the airflow in the bin*).

The fine material distribution in the grain mass and the air velocity at the center and side locations in the bin were quantified for several NA/LT in-bin drying field tests. The best management practices (BMPs) of leveling the grain peak after filling the bin and coring the grain mass were performed, and the improvement on the airflow distribution was quantified. The non-uniformity factor of the airflow (NUF) was proposed as an index to quantify the non-uniformity of the airflow rate in the bin. It was shown that when the grain peak was not leveled, the average NUF was 89%. When the grain peak was leveled, the NUF was reduced to 36%. The nonuniform airflow rate in the experiments in which the grain peak was leveled was related to the higher concentration of fine material in that location of the bin (232% more fines at the center than at the side of the bin). It was also shown that the coring operation reduced the concentration of fine material at the center of the bin, and improved the distribution of the airflow rate. PHAST-FDM was enhanced to simulate center and side differential airflow rates.

The effect of BMPs on the performance of NA/LT in-bin drying systems was further investigated using 40 years of hourly weather data for four different locations in the Midwestern Corn Belt (North Platte, Nebraska; Des Moines, Iowa; Indianapolis, Indiana; and Evansville, Indiana). Based on simulation results, it was determined that the operators of NA/LT in-bin drying systems could reduce the drying costs from 25 to 33% by leveling the grain peak after loading the bin. An additional savings of 18 to 22% could be achieved by installing effective grain (and FM) distributors or by coring the grain mass. The total overall drying cost savings gained from applying these simple BMPs ranged from 39 to 49%. The savings were more significant in the Northern and Western regions (North Platte, Nebraska and Des Moines, Iowa) than in the Southern and Eastern regions (Indianapolis, Indiana and Evansville, Indiana) of the Midwest Corn Belt. The predicted improvements due to the implementation of the BMPs were greater than expected and had never been documented previously.

4. Practical impacts of research efforts.

a. Short Term Impacts

On the basis of the results of this research, The GSI Group (Assumption, Il) developed the DryNStore fan and burner controller for the in-bin drying and conditioning of corn. This controller will be commercialized during the 2006 drying season. The DryNStore controller has incorporated the SAVH fan and burner control strategy (developed under Objective 2). The DryNStore fan and burner controller has the capability of targeting a specific final MC, minimize the overdrying of the grain bottom layer, minimize drying cost and self adapt its settings to a broaden rage of weather conditions.

b. Long Term Impacts

It is expected that, as a result of this work, a greater number of farmers will be interested in implementing NA/LT in-bin drying systems in their facilities, with the resulting benefit of better grain quality for the U.S. food corn processing industry.

The research presented in this report was concluded in the spring of 2006. The following publications have been submitted for peer review or are in preparation for submission:

Bartosik, R.E. and Maier, D.E. (2006). Effect of airflow distribution on the performance of NA/LT in-bin drying of corn. Transactions of the ASAE. 49(4):… In press.

Bartosik, R.E. and Maier, D.E. (2006). Study of the adsorption and desorption equilibrium relationships for three different corn types using the Modified Chung-Pfost equation. Submitted to Transactions of the ASAE. December 2005. In review.

Bartosik, R.E. and Maier, D.E. (2006). Field implementation and model validation of a model-based fan and burner control strategy for the in-bin drying and conditioning of corn. Submitted to Applied Engineering in Agriculture. December 2005. In review.

Bartosik, R.E. and Maier, D.E. (2006). Evaluation of the SAVH strategy for in-bin drying of corn in different locations of the Midwest. To be submitted to Transaction of the ASAE.

Bartosik, R.E. and Maier, D.E. (2006). Effect of non-uniform distribution of fine material and airflow rate on NA/LT in-bin drying performance. To be submitted to Transaction of the ASAE.

Bartosik, R.E. and Maier, D.E. (2006). Effect of drying characteristics of yellow dent, white and waxy corn types on NA/LT in-bin drying performance. To be submitted to Transaction of the ASAE.