Air and Rice Property Profiles Within a Commercial Cross-Flow Rice Dryer

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ABSTRACT

A commercial cross-flow dryer was tested during the 2001 and 2002 rice harvest. The objectives were to record air temperature and relative humidity (RH) data at strategic locations throughout the dryer and obtain samples for rice moisture content (MC) and head rice yield (HRY) analysis at the end of each drying run from sampling locations within the rice column. Results showed a psychrometric relationship between air temperature and RH as drying air passed through the rice column. Air temperature decreased rapidly into the rice column while RH correspondingly increased. Grain exchanger effects were indicated by changes in air temperature, RH, and rice MC profiles across the drying column at the sampling elevations above and below a grain exchanger. Rice samples collected next to the hot-air plenum (HAP) showed a relationship between HRY and MC reductions; larger rice MC reductions in the dryer resulted in larger HRY reductions.

INTRODUCTION

Air temperature, RH, and rice MC are variables that greatly affect the drying of rough rice. During drying, Jia et al. (2002) showed that the air temperature surrounding a rice kernel could be assumed to equal the kernel temperature within 1.5 minutes of exposure. Although the designs for cross-flow dryers are not all the same, rice for most commercial cross-flow dryers will be exposed to an air condition for several minutes

1 This is a completed study.
before being mixed by a grain exchanger. These devices are used to mix and transfer grain from the heated-air side to the exhaust side of grain columns as it flows through the dryer.

A drying hypothesis using kernel temperature and MC and principles of polymer chemistry has become a key focus of recent research to explain rice-fissure formation (Cnossen and Siebenmorgen, 2000; Cnossen et al., 2002). This glass-transition hypothesis is based on the material "state" of localized regions of the kernel relative to the kernel glass-transition temperature (Tg). Although RH is not used to determine Tg directly, it is important in determining the kernel MC. At a certain air temperature and RH, an equilibrium moisture content (EMC) can be determined for a particular grain (Stroshine and Hamann, 1994). The rate of drying for a kernel is greatly affected by the difference between its MC and the kernel EMC associated with the drying-air temperature and RH; a greater difference will produce a greater drying rate. Although rapid drying may be more effective in removing moisture, the kernel may be damaged resulting in a reduced HRy if excessive MC gradients are induced within the kernel (Cnossen and Siebenmorgen, 2000). Drying should therefore consist of finding the optimal drying-air condition that maximizes drying rates yet maintains high HRys.

No previous research was found that obtained air/kernel data within the grain column of a commercial cross-flow dryer. Otten et al. (1980) predicted air temperature, RH, and rice MC profiles within the grain column of a commercial cross-flow dryer; however, no experimental data within the grain column were obtained for comparison. The objectives of the study reported herein were to measure and record air temperature and RH data at strategic locations throughout a commercial cross-flow dryer and obtain samples for rice MC and HRy at the end of each drying run from the sampling locations in the rice column to determine changes in rice quality.

**MATERIALS AND METHODS**

Sensors (Hobo, Onset Computer Corporation, Bourne, MA) to measure air temperature and RH were placed in a commercial cross-flow dryer at Jonesboro, Arkansas, during the 2001 and 2002 rice harvests. The sensors had a temperature range from –20 to 70°C with an accuracy of ±1°C and a measuring RH range from 25 to 95% with an accuracy of ±5%. The sensors were equipped with data-recording capability, eliminating the need for a data logger. Three elevations approximately 6 m apart were chosen for the 2001 testing runs (Fig. 1). At each elevation three sensors were placed equidistant across the 38 cm column of rice. A fourth sensor at each elevation was placed in the HAP. For the 2002 harvest, a fourth elevation was included immediately below grain exchanger 1. Even though this new sampling elevation was the second sampling elevation the rice encountered after entering the top of the dryer, this elevation was referred to as elevation 4 since it was not included in the 2001 testing. An additional sensor located at the air inlet to the heated-air fan measured ambient air conditions.

Sensors could not be placed directly into the rice column due to the force created by the flow of the rice as it moved downward through the dryer. Instead, for sensor
placement and sample collection, three 5-cm (i.d.) galvanized pipes were welded to the edge of the rice column end wall (Fig. 2) and were spaced equidistant across the rice column at each elevation (Fig. 1). The pipe ends extending from the wall were threaded to allow a perforated cap to be easily secured or removed for rice-sample collection at the conclusion of a test run. The cap was perforated to allow movement of air through the pipe. To prevent rice from residing in the pipe, a perforated 5-cm (o.d.) plug was placed inside the pipe. The length of the plug was the same length as the pipe to prevent any rice from entering the pipe; this ensured that readings from a sensor were of the air passing through the pipe at a particular rice column location and not of the air passing through stagnant rice in the pipe. The sensors were placed inside the perforated plugs as illustrated in Fig. 2.

Each test run comprised drying a certain lot of rice that took about eight hours to pass through the dryer. Typically, a lot is passed through the dryer several times to reduce the rice MC to between 12 and 13%. Testing primarily consisted of first-pass rice in which more of an effect due to drying could be observed than in subsequent passes. At the end of each test, the caps and plugs were removed from the sampling ports to first retrieve the sensors. Once the cap and plug were removed from a sampling port in the rice column, the pressure created by the column of rice and the flow of air through the pipes produced a steady stream of rice exiting the ports from which samples for rice MC and HRY were taken. Additional samples for MC and HRY were obtained at the end of each test run at the dryer inlet and exit to determine an overall effect on quality due to drying.

RESULTS

Figure 3 shows the air temperature and RH history from the sensors at elevation 1 (Fig. 1) for the 1 October 2001 test run. A constant RH (4%) in the HAP was estimated in the HAP because readings were below the measuring RH range of the sensors.\(^1\) Changes in sensor readings within the rice column could be attributed to variation in rice MC entering the dryer since negligible changes in temperature readings were observed in the HAP.

Air temperature and RH readings at 1:30 AM (Fig. 3) were used to illustrate a profile across the rice column (Fig. 4). A psychrometric relationship can be observed between these two air parameters. Decreasing air temperatures into the rice column were associated with increasing RHs. This can be explained by evaporative cooling occurring as part of the drying process. Sensible energy is transferred from the air to evaporate moisture from the kernels, thereby cooling the air and increasing the RH.

Grain exchanger 1 effects can be seen in Fig. 5, which shows the air temperature and RH readings at 12:00 AM for the 11 September 2002 testing run. At elevation 4 the temperature reading of the sensor located near the exhaust (35°C) was higher than the

\(^{1}\) The RH in the HAP was determined from the sensor measurements of ambient air conditions using a psychrometric chart.
temperature readings of the sensor located near the HAP (30ºC) and the sensor located in the center of the rice column (30ºC). Correspondingly, the RH 9.5 cm from the exhaust (63%) was lower than the RH near the HAP (85%) and at the center of the rice column (88%). Although it is not completely clear how the rice is mixed within grain exchanger 1, a portion of the rice located near the HAP above the grain exchanger was switched to the exhaust side since a higher temperature and a lower RH reading were observed near the exhaust at elevation 4.

Grain exchanger effects were also observed in the rice MC profiles. Figure 6 reports the rice MCs for the various sampling locations (Fig. 1) obtained at the end of the 11 September 2002 testing run. At elevation 1, before rice encountered a grain exchanger, lower rice MCs were observed next to the HAP. Rice entered the dryer at 16.3% MC, which was also the MC observed for the rice sampled closest to the exhaust at this elevation. The MC of the rice sampled in the center of the rice column was 16.0% and was 14.1% for the rice sampled near the HAP. This profile was not observed at elevation 4, located immediately below grain exchanger 1. Instead, Fig. 6 shows that the highest MC (16.1%) at this elevation was for the rice sampled near the HAP while the lowest MC (14.4%) was for the rice sampled near the exhaust.

Grain exchanger 1 effects can still be observed at elevation 2, which is located 4 m from elevation 4. The MC of the rice sampled in the center of the rice column at elevation 2 (15.2%) was higher than the rice MC sampled near the exhaust (14.2%). This same pattern was observed with the RH readings at this elevation; however, the air temperature readings did not appear to be affected by the grain exchanger (Fig. 5). At elevation 2, the RH (85%) in the center of the rice column was higher than the RH (61%) 9.5 cm from the exhaust while the air temperatures at these two locations were both about 33 to 35ºC. Due to the fact that heat transfer in kernels is much faster than mass transfer, it is postulated that although there was sufficient drying time for the temperature readings at elevation 2 to show a similar trend to elevation 1, more time was still needed for the RH and rice MC profiles to experience this behavior.

HRY data reported in Fig. 6 for the 11 September 2002 testing run showed an overall reduction of 3.5 percentage points between the rice entering and exiting the dryer. Rice entering the dryer had an HRY of 64.9% while rice exiting had a 61.4% HRY. Except for elevation 4, the lowest HRYs at an elevation were observed at the sampling locations next to the HAP, which was also where the lowest rice MCs per elevation were reported.2 This was corroborated by Gustafson and Morey (1981) who reported that corn located next to the HAP was the first to increase in breakage susceptibility, which increased as MC decreased for the dried corn. The sampling location at elevation 3 next to the HAP reported the lowest reading in HRY (49.1%) throughout the dryer. This was also where the lowest rice MC (12.3%) was reported.

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2 Although not shown by a figure, an additional experiment showed that rice exiting the sampling ports 9.5 cm from the HAP was actually rice located closer to the HAP.
SIGNIFICANCE OF FINDINGS

Drying experiments conducted at the laboratory scale have shown relevance in explaining rice quality reductions; however this work was needed to measure key parameters in commercial rice dryers. These data will be used to evaluate the glass-transition hypothesis and to validate models predicting air and rice conditions inside dryers. This will lead to maximizing the drying capacity of dryers while minimizing quality reduction.

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LITERATURE CITED


Fig. 1. Design layout for the temperature and relative humidity sensor locations in the cross-flow rice dryer for the 2001 and 2002 test runs. Elevation 4 was not included during the 2001 testing.

Fig. 2. Schematic of a sampling port.
Fig. 3. Air temperature (A) and relative humidity (B) history at elevation 1 (Fig. 1) during the 1 October 2001 test run. The relative humidity in the HAP (4%) was estimated based on the air-inlet temperature and relative humidity.
Fig. 4. Air temperature and relative humidity profiles at elevation 1 (Fig. 1) at 1:30 AM for the 1 October 2001 testing run illustrated in Fig. 3.

Fig. 5. Air temperature (T) and relative humidity (RH) data for various locations within the cross-flow dryer at 12:00 AM for the 11 September 2002 testing run. RHs reported in the hot-air plenum were estimated using air inlet temperature and RH.
**Fig. 6.** Moisture content (MC) (w.b.) and head rice yield (HRY) data for various locations within the cross-flow dryer for the 11 September 2002 testing run.