Ambient Air Drying of English Walnuts

Tom Rumsey, Jim Thompson
MEMBER ASAE ASSOC. MEMBER ASAE

ABSTRACT

MOST English walnuts in California are dried on a farm in batch dehydrators. The drying season lasts from September through the end of October. Heated air, at temperatures up to 43°C, is forced through the fixed bed dryers. Temperatures above 43°C will cause oil in the nut meat to become rancid (Woodroof, 1978). The initial moisture content of the nuts ranges from 15 to 50% (dry basis), and they are required to be dried to 8.7%.

Due to increasing energy costs and scarcity of fuel supplies, research into natural air drying of walnuts was started at the Agricultural Engineering Department at the University of California in 1977 (Thompson et al., 1978). Initial field trials showed the feasibility of drying walnuts with ambient air. The drying times were longer, but there were no signs of deterioration of nut quality.

A second phase of the project has been to modify a grain drying simulation computer program to model walnut drying. The program modified was the Michigan State University fixed bed grain drying program (Bakker-Arkema et al., 1974). This paper describes the modifications that were made, and compares results predicted by the model to field drying tests. The model was used to simulate ambient air drying at three walnut growing locations in California.

MATHEMATICAL MODEL

The four equations that describe fixed bed drying are given in Brooker et al. (1974). The unknowns are air temperature, humidity, walnut temperature and moisture. At low air flow rates, such as those used in batch walnut drying, the walnut and air temperatures are nearly the same. Preliminary simulation runs using all four equations showed that the predicted walnut and air temperatures were within 0.5°C of each other. This has also been observed in laboratory walnut drying experiments. Similar results in cereal grain drying have been observed by other researchers (Bakker-Arkema et al., 1977). Because of this, the product and air temperatures were assumed to be equal and the number of equations reduced by one. The resulting equation for temperature is

\[
\frac{\partial T}{\partial t} = \frac{G_a}{\rho_p (c_p + c_w M)} \frac{\partial X}{\partial X} - \frac{G_a h_{fg}}{\rho_p (c_p + c_w M)} \frac{\partial H}{\partial X} \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots 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\cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cd - 895, 1984)
were put on disk files. A four point interpolation routine was used to find intermediate results.

The initial uniform walnut moisture content was 33.3% (dry basis) and drying was terminated when the moisture content reached 8.7% on top of the bed. The bed was 1.22 m deep. Preliminary results indicated that an air flow rate per unit bed volume of 25.0 (m³/min)/m³ was a good compromise between drying time and fan energy requirements. Fan energy use was calculated from empirical equations developed by Rumsey (1981).

Drying simulations were started at noon on the 1st and 16th of each month. If the walnuts had not finished drying within 148 h, the simulation run was terminated. Preliminary tests indicate that mold growth may begin if drying is not completed within this time. Also, the required dryer space becomes prohibitive with large drying times.

RESULTS

Experimental Drying Tests

A summary of test conditions and results for the experimental drying tests are given in Table 1. The initial moisture contents decreased with later harvest dates. During the 1979 tests, walnuts harvested on September 26th had a moisture content of 36.3% while those harvested on October 29th were at 14.3%. This is a phenomenon that has been noted in walnut production. For most years, little drying is required at the end of the harvest season.

Air flow rate per unit bed volume ranged from 10. to 12. m³/s-m³ in the 1979 tests. This corresponded to the flow rates recommended by Thompson et al. (1978). During the 1980 tests, the air flow was kept at 24. m³/s-m³ which is in the range recommended for heated air drying (Thompson, 1981).

Test runs were ended when the average moisture content was near 8.7% or when rainy weather conditions halted drying. Test numbers 79-2, 79-3 and 79-5 were all stopped because of rain.

Measured and predicted final average bed moisture contents are given in the last column of Table 1. The average difference between measured and predicted final moisture is 0.28% with a standard deviation of 1.25%. Plots of measured and predicted average bed moisture versus time for test 79-1 are given in Fig. 1. The drying rate is much faster during daylight hours due to higher ambient temperatures and lower relative humidities.

Predicted and measured moisture content profiles for tests 79-1 and 79-4 are given in Figs. 2 and 3 respectively. Predicted and measured profiles after 48 hours of drying were within 2% for test 79-1 and 1% for test 79-4. At the end of the tests, the model consistently underpredicted the moisture profile by about 2.5% for test 79-1 while it...
was still within 1% for test 79.4.

All of the above theoretical results were made without allowing rewetting. When rewetting was allowed, the model consistently overpredicted the final average bed moisture content by an average of 3.2%.

**Drying Simulations**

A summary of the results from the simulations are given in Table 2. A simulation was counted as successful if drying was completed within 148 h. For the first three starting dates, there were only three cases when the drying was not completed. In all of these cases, rain occurred during the drying period, and the resulting high humidities and low dry bulb temperatures would not allow drying to be completed in the required time. The success rate was lower on the October 16th starting date at all three locations. This was usually due to rain and periods of fog. For some clear days, the equilibrium moisture content corresponding to the minimum ambient humidity was always higher than the desired 8.7% moisture content.

Average drying times were lowest for the September 1st starting date, ranging from 37.8 h at Red Bluff to 64.3 h in Sacramento. Average drying times were higher by 10 to 20 h at Sacramento for all starting times except October 1st when the average was the same as that for Fresno.

Average fan energy requirements ranged from 9.32 to 22.7 kW-h/t. At 5 cents per kW-h, the corresponding electrical energy costs range from 47 cents to $1.14/t (metric ton). This represents a savings of over $12/t over the average 1981 costs of $13.75/t for walnuts dried with heated air (Thompson, 1981).

**CONCLUSIONS**

A fixed bed grain drying computer program has been modified to successfully model ambient air walnut drying. Drying times and moisture profiles predicted by the model agree with field experiment results.

The performance of ambient air walnut drying systems were evaluated with the model at Red Bluff, Sacramento and Fresno using eleven years of weather data. Ambient drying appears to be feasible until mid-October. Energy cost savings of about 90% are possible. Low temperatures and high relative humidities after October 16 would usually require auxiliary heaters to complete drying.

**References**


**TABLE 2. AMBIENT DRYING SIMULATION RESULTS.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Red Bluff</th>
<th>Sacramento</th>
<th>Fresno</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date</td>
<td>9/1</td>
<td>9/16</td>
<td>10/16</td>
</tr>
<tr>
<td>Ave. dry time, h</td>
<td>38</td>
<td>63</td>
<td>58</td>
</tr>
<tr>
<td>Max. dry time, h</td>
<td>72</td>
<td>140</td>
<td>100</td>
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<tr>
<td>Min. dry time, h</td>
<td>27</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>Ave. energy, kWh/t</td>
<td>8.45</td>
<td>14.2</td>
<td>12.9</td>
</tr>
</tbody>
</table>

*Number of years for which drying was completed within 148 hours.
†Does not include unsuccessful years.
Thin-layer drying and equilibrium moisture content equations for Ashley walnuts. ASAE Paper 80-6507, ASAE, St. Joseph, MI 49085.


NOMENCLATURE

Variables

\[ B = \text{rate constant in thin layer equation, } 1/h \]
\[ c = \text{specific heat, } \text{kJ/kg}^\circ\text{C} \]
\[ G = \text{dry weight flow rate per unit bed cross sectional area, } \text{kg/h-m}^2 \]
\[ h_v = \text{heat of vaporization, } \text{kJ/kg} \]
\[ H = \text{humidity ratio, } \text{kg/kg} \]
\[ M = \text{moisture content, dry basis, } \text{kg/kg} \]
\[ M_e = \text{equilibrium moisture content, dry basis, } \text{kg/kg} \]
\[ M_i = \text{initial moisture content, dry basis, } \text{kg/kg} \]
\[ \text{rh} = \text{relative humidity, decimal} \]
\[ T = \text{both air and product temperature, } ^\circ\text{C} \]
\[ t = \text{time, h} \]
\[ x = \text{bed depth coordinate, m} \]
\[ \rho = \text{dry weight density, } \text{kg/m}^3 \]

Subscripts

\[ a = \text{air} \]
\[ p = \text{product} \]
\[ v = \text{vapor} \]
\[ w = \text{water} \]