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**Abstract**

A computer simulation model was developed to model summer preparation of desiccant corn using heat from solar collectors. The desiccant provides a storage medium for solar energy in the form of drying potential and is blended with wet corn at harvest. Grain-mass/collector-area ratios from 0.27 to 8.5 t/m2 (1.0 to 31 bu/ft2) and airflow rates from 0.0019 to 0.093 m3/s-t (0.1 to 5 cfm/bu) were studied. The use of a solar collector during the summer is desirable because solar radiation is available more hours per day, the drying potential is good, and the solar collector use period is increased. The desiccant corn is blended with wet corn in the fall to reduce the average moisture content of the wet corn, therefore reducing the electrical energy to dry and reducing the spoilage risk of the wet corn. Based on the simulation results, an airflow rate of 0.014 m3/s-t (0.75 cfm/bu) along with a grain-mass/collector-area ratio between 3 and 5.5 t/m2 (11 and 20 bu/ft2) is recommended. This airflow rate and the grain-mass/collector-area ratio range will achieve a corn desiccant moisture of 8 to 10% with an acceptable collector size and electrical energy input.

**Disciplines**

Agriculture | Bioresource and Agricultural Engineering

**Comments**

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ABSTRACT

A computer simulation model was developed to model summer preparation of desiccant corn using heat from solar collectors. The desiccant provides a storage medium for solar energy in the form of drying potential and is blended with wet corn at harvest. Grain-mass/collector-area ratios from 0.27 to 8.5 t/m² (1.0 to 31 bu/ft²) and airflow rates from 0.0019 to 0.093 m³/s·t (0.1 to 5 cfm/bu) were studied.

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Based on the simulation results, an airflow rate of 0.014 m³/s·t (0.75 cfm/bu) along with a grain-mass/collector-area ratio between 3 and 5.5 t/m² (11 and 20 bu/ft²) is recommended. This airflow rate and the grain-mass/collector-area ratio range will achieve a corn desiccant moisture of 8 to 10% with an acceptable collector size and electrical energy input.

## INTRODUCTION

The purpose of this study was to develop recommendations for desiccant preparation using a combination desiccant/low-temperature corn drying system in which overdried corn is used as the desiccant. The system was designed to improve the cost effectiveness of a solar collector by prolonging its use period. In addition to fall grain drying, the solar collector is used in summer to overdry corn from the previous harvest. Solar energy is stored in the form of drying potential in overdried corn which is mixed with wet corn at harvest. Bern et al. (1981) described the system and present field test results, but they do not provide sufficient information to make recommendations on the desiccant preparation procedure.

A computer simulation model was developed to study desiccant preparation with various collector sizes, airflow rates, and weather conditions. An optimum system would:

- dry corn to a moisture content low enough for use as a desiccant
- use minimum electrical energy for fan operation
- require minimal solar collector area.

Using these criteria, simulation results were used to develop recommendations for desiccant preparation in future field tests.

## COMPUTER SIMULATION MODEL

### Grain Drying

The grain drying portion of the computer model is a modification of Thompson's natural-air drying model (Thompson, 1972). Thompson's model was modified to simulate drying performance assuming that the drying fan was controlled by a series-connected solar radiation detector-humidistat combination that responded to 3-h average weather conditions. Other assumptions made in the analysis were:

- Desiccant preparation began on May 1 (Julian day 121) with 15% (moisture content wet basis)* corn.
- Drying continued until the difference between the moisture content of the top layer of corn and the moisture content of corn at equilibrium with the drying air was less than 0.5 points or until September 30 (Julian day 273), whichever came first.
- The drying fan operated only when ambient relative humidity was under 55% and solar radiation on a horizontal surface exceeded 275 W/m².
- The solar collector caused negligible airflow resistance.

### Solar Collector

For the simulation studies, a solar coefficient was used to describe collector performance. The solar coefficient (SC) is defined as airstream temperature rise (°C) produced by the solar collector when solar insolation equals 824.47 W/m² at the collector tilt angle.†

$$SC = \frac{(824.47)\Delta t}{I} \quad [1]$$

where

SC = solar coefficient, °C

I = solar insolation at collector tilt angle, W/m²

Δt = airstream temperature rise produced by the solar collector, °C

For specified values of SC, Δt can be calculated using equation [1] with values of I from weather data.

The temperature rise from a solar collector is described in equation [2].

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*All moisture contents are expressed on a wet basis.

†Pierce and Thompson (1979) assumed a reference solar energy rate of 1000 langley/day (11625 W·h/m² day). The average length of daylight during the desiccant preparation period from May 1 to September 20 was chosen to be (11625/14.1) = 824.47 W/m².

  

$$\Delta t = \frac{IA\eta}{Q(1210.4)} \quad [2]$$

where

$\Delta t$ = airstream temperature rise produced by the solar collector, °C
I = solar insolation at the collector tilt angle, $W/m^2$
A = effective collector absorber area, $m^2$
$\eta$ = collector efficiency, decimal
Q = total airflow rate through the collectors, $m^3/s$

By substituting equation [2] into equation [1], the solar coefficient is defined by other collector variables. Equation [3] shows how SC can be computed for existing collectors.

$$SC = \frac{(0.6811)A\eta}{Q} \quad [3]$$

where

A = effective collector absorber area, $m^2$
$\eta$ = collector efficiency, decimal
Q = total airflow rate through the collectors, $m^3/s$

### Independent Variable Selection

**Weather:** System performance was analyzed using weather data for two years, 1972 and 1976. These years represent extremes of recent desiccant preparation weather conditions in Iowa. May through September of 1972 had low dry bulb temperatures and solar radiation and high relative humidities. At the other extreme, dry bulb temperatures and solar radiation levels were high and relative humidities were low in 1976. Simulation of the desiccant preparation process with weather data from these years was assumed to yield system boundaries. Data from 1978 through 1981 tests of corn desiccant preparation near Ames, Iowa (Bern et al., 1981) were compared with simulation results. Field data were shown on each figure wherever field conditions were similar to simulation assumptions. Des Moines, Iowa weather data and Ames, Iowa solar insolation data represent the data base for the simulation (Ames is 60 km north of Des Moines).

**Grain-mass/collector-area:** The size of the solar collector used in proportion to the quantity of desiccant prepared has a large effect on system cost and effectiveness. Five grain-mass/collector-area ratios were chosen for analysis, 0.27, 1.2, 3.2, 4.3, and 8.5 $t/m^2$. Three ratios were studied in depth and two others were used to identify boundary conditions. Collector size was held constant for all simulations and grain quantity was varied to obtain the different grain-mass/collector-area ratios. The solar collector used in the simulations and field tests consisted of two identical 11.9-$m^2$ suspended-plate units. Each unit was 1.22-m by 9.75-m, with a corrugated green house-grade fiberglass cover, corrugated metal absorber, 0.0334-W/m·K (R = 4.31) side and backplate insulation, and 6.4-mm chipboard backplate. Performance for this type of collector was reported by Wilcke et al. (1979). Solar coefficients for the field test collector ranged from 4 to 8, depending on the collector efficiency and airflow rate (equation [3]).

**Fan energy requirement:** A 4.6-m corn depth was used for all simulations. Static pressure was predicted by applying a 1.5 pack factor to Shedd's data (Shedd, 1953). Van Ee and Kline's (1979) fan equation with an assumed 85% fan efficiency was used to calculate the required fan power. The simulation program kept track of fan hours and then calculated electrical energy use by multiplying fan hours by fan power.

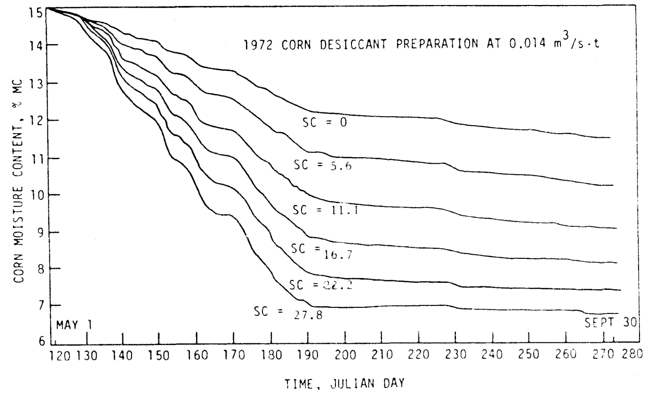


**Fig. 1—Corn moisture content vs. time for 1972 solar corn desiccant preparation in central Iowa.**

## SIMULATION RESULTS

### Analysis

**Solar coefficient:** Figs. 1 and 2 show the simulated desiccant drying progress with various solar coefficients for 1972 and 1976, respectively. As expected, final moisture content decreases as solar coefficient increases. With an airflow rate of 0.014 $m^3/s \cdot t$ (0.75 cfm/bu)‡§, most of the drying takes place by the middle of July.

**Airflow rate:** Figs. 3 and 4 illustrate the effect of airflow rate on desiccant drying rate. The two sets of curves represent two different grain-mass/collector-area ratios. In practical terms, the different ratios represent different bin diameters, because collector size and grain depth were held constant. The solar coefficient was calculated for each airflow rate using equation [3] and efficiencies from Wilcke et al. (1979). The drying rate was defined as the average change in corn moisture content per day, over the first 47 days of desiccant preparation. Because the shortest grain drying simulation was completed in 47 days (SC = 27.8 in Fig. 2), the drying rate base was chosen to be 47 days.

The drying rate increases with increasing airflow rate to a peak at approximately 0.028 $m^3/s \cdot t$ (1.5 cfm/bu).

‡1 t = 1000 kg @ 15.5% moisture
§1 bu = 56 lb @ 15.5%

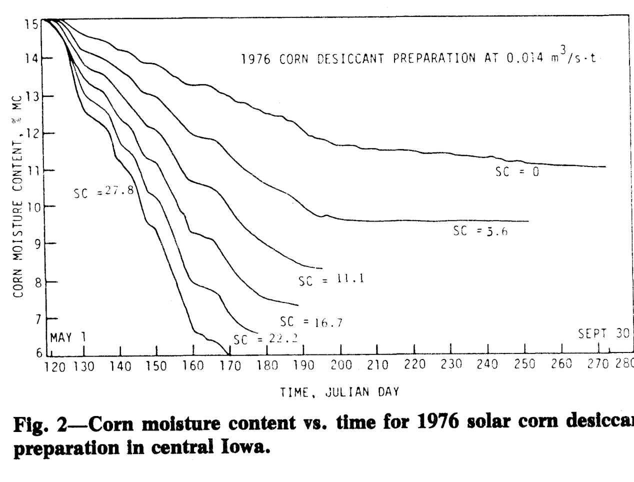


**Fig. 2—Corn moisture content vs. time for 1976 solar corn desiccant preparation in central Iowa.**

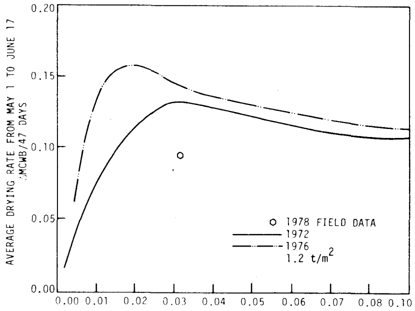


**Fig. 3—Average drying rate vs. airflow rate for a grain-mass/collector-area ratio of 1.2 t/m² (central Iowa).**

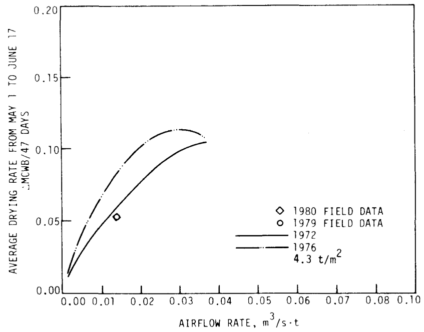


**Fig. 4—Average drying rate vs. airflow rate for a grain-mass/collector-area ratio of 4.3 t/m² (central Iowa).**

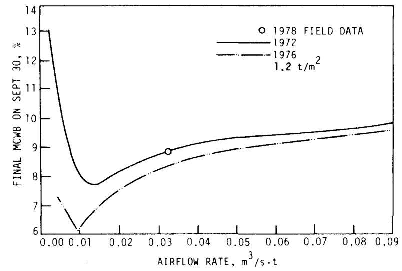


**Fig. 5—Final grain moisture content vs. airflow rate for grain-mass/collector-area ratio of 1.2 t/m² (central Iowa).**

Drying rate decreases at greater airflow rates because the grain reaches equilibrium with drying air earlier in the season when equilibrium moisture contents are higher. Drying rate also decreases with increasing grain-mass/collector-area ratio. This is to be expected because drying air temperatures are lower at the high mass/area ratios with equivalent airflow rates.

A data point from the 1978 field test is plotted on Fig. 3 and points from the 1979 and 1980 tests are plotted on Fig. 4. Because the weather data for 1978 through 1980 lie between the extremes of 1972 and 1976, you would expect the field test data to fall between the two simulation curves. The points for 1979 and 1980 are close to the simulated data, but the 1978 point lies below the curves. The discrepancy can be explained by the late desiccant preparation starting date in 1978. The drying fan was not switched on until June 7 in 1978, while the simulations are based on a May 1 starting date.

Figs. 5 and 6 show desiccant moisture content versus airflow rate for two different grain-mass/collector-area ratios. Using 1976 weather data, the minimum moisture content was achieved at 0.009 m³/s·t (0.5 cfm/bu) for both ratios. With 1972 data, minimum desiccant moisture content occurred at about 0.014 m³/s·t (0.75 cfm/bu). Data points for the 1978 through 1980 field tests fell on or between the curves.

Figs. 7 and 8 indicate the effect of airflow rate on fan electrical energy consumption per unit grain mass. Fan energy represents either the kWh used between May 1 and the time the corn reached moisture equilibrium with the drying air, or if the corn did not come to within 0.5 points of moisture equilibrium with the drying air, the total kWh used between May 1 and Sept. 30. Electrical energy increases as airflow rate increases, even though fan hours decrease. The larger fans dry the desiccant faster, but require disproportionately more power. The 1978 and 1979 field data points fall within the expected range. Field data from 1980 (Fig. 8) indicate a slightly higher fan energy requirement. The beginning date for desiccant preparation in the simulation program was May 1 but in the 1980 field test, desiccant preparation began on March 25, thereby increasing the time the fan operated. Therefore, we expect the field data point to indicate a higher kWh/t of grain prepared. Without the additional fan energy used from March 25 through May 1, the resulting data point would be very close to the 1979 field data point of Fig. 8.

Figs. 9 and 10 show the electrical energy for fan operation required to remove a unit mass of water from corn as a function of airflow rate. As airflow rate increases, more and more energy per unit of water is required. With a 1.2 t/m² desiccant preparation system, favorable weather conditions may greatly reduce the electrical energy use per kg of water removed (Fig. 9). Apparently weather conditions do not have much effect on energy use when the grain-mass/collector-area ratio is as high as 4.3 t/m² (Fig. 10). This seems to indicate the solar collector will significantly reduce the electrical energy for fan operation in a sunny year. Field test data for 1978, 1979 and 1981 compare very well with the simulation results (Figs. 9 and 10).

**Grain-mass/collector-area ratio:** Fig. 11 shows the final desiccant moisture content achieved in 1972 and 1976 at two different airflow rates, for several grain-mass/collector-area ratios. As expected, final moisture content increases as grain-mass/collector-area ratio increases. An infinite ratio corresponds to natural air drying (no solar collector). The sensitivity of final moisture content to weather conditions seemed to be a function of airflow rate. At every grain-mass/collector-

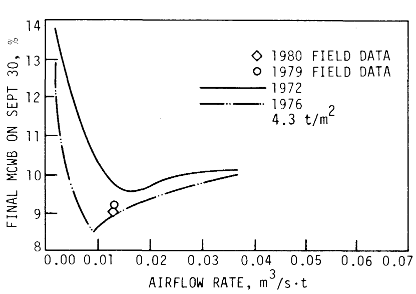


**Fig. 6—Final grain moisture content vs. airflow rate for grain-mass/collector-area ratio of 4.3 t/m² (central Iowa).**

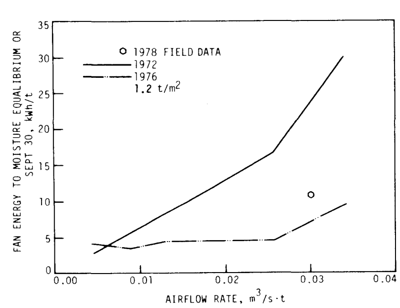


**Fig. 7—Electrical energy for fan operation per unit grain mass vs. airflow rate for a grain-mass/collector-area ratio of 1.2 t/m² (central Iowa).**

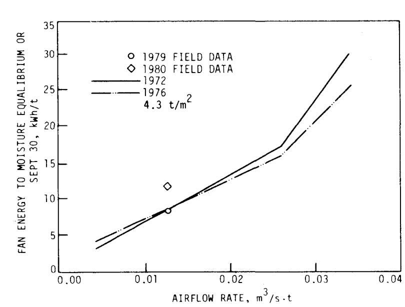


**Fig. 8—Electrical energy for fan operation per unit grain mass vs. airflow rate for a grain mass/collector-area ratio of 4.3 t/m² (central Iowa).**

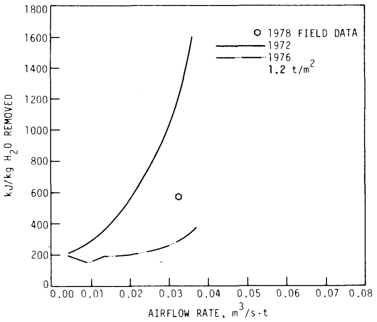


**Fig. 9—Electrical energy for fan operation per unit of water removed for a grain-mass/collector-area ratio of 1.2 t/m². Grain depth: 4.6 m (central Iowa).**

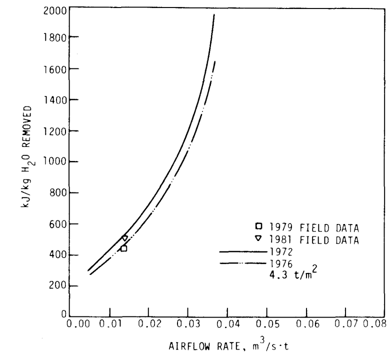


**Fig. 10—Electrical energy for fan operation per unit of water removed for a grain-mass/collector-area ratio of 4.3 t/m². Grain depth = 4.6 m (central Iowa).**

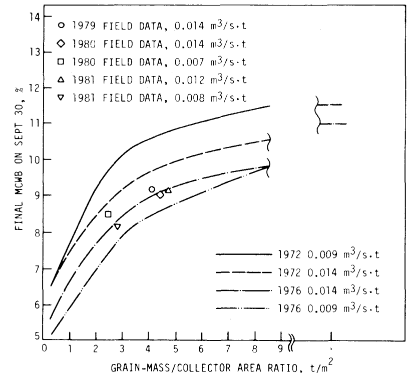


**Fig. 11—Final average grain moisture vs. grain-mass/collector-area (central Iowa).**

area ratio simulated, the final moisture content range was greater at lower airflow rates. The system with an airflow rate of 0.009 m³/s·t (0.5 cfm/bu) produced wetter desiccant in unfavorable years (1972) and drier desiccant in favorable years (1976). Field data from 1979 through 1981 fell well within the outer simulation bounds of a 0.009 m³/s·t airflow rate and very close to the inner simulation bounds of a 0.014 m³/s·t airflow rate.

The electrical energy for fan operation required to remove a unit of water from the grain for systems with various grain-mass/collector-area ratios at two airflow rates is plotted in Fig. 12. Electrical energy requirements are low at either airflow rate compared with conventional drying systems. Slightly more electrical energy is used by the system with 0.014 m³/s·t (0.75 cfm/bu) airflow rate than with a 0.009 m³/s·t (0.5 cfm/bu) airflow rate. Electrical energy requirements generally increase with increasing grain-mass/collector-area ratios. The dashes at the right indicate the electrical energy required with no solar collector.

Fig. 13 is a plot of the average cost to remove 1 kg of water for various grain-mass/collector-area ratios. The total cost to remove 1 kg of water was calculated by adding an annual equivalent cost for the solar collector to the cost for electrical energy used, and dividing the sum by the kg of water removed. The following assumptions were made:

| | |
|---|---|
| airflow rate | 0.014 m³/s·t (0.75 cfm/bu) |
| collector cost | \$6.14/yr·m² (Kline and Odekirk, 1979) |
| electrical energy | \$0.05/kWh |
| corn depth | 4.6 m |
| collector area | 23.8 m² |

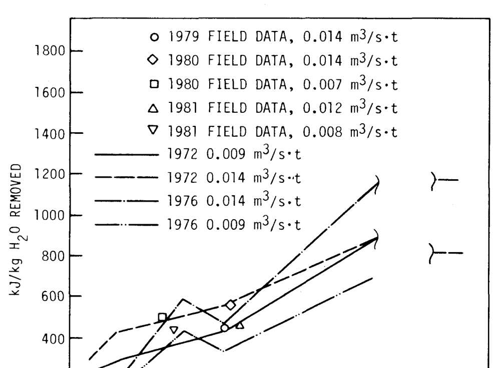


**Fig. 12—Electrical energy for fan operation vs. grain mass/collector-area (central Iowa).**

## SUMMARY

Final desiccant moisture content is a function of weather, airflow rate, and grain-mass/collector-area ratio. In this study, the lowest desiccant moisture contents were obtained with low grain-mass/collector-area ratios, 1976 weather data, and airflow rates between 0.009 m³/s·t (0.5 cfm/bu) and 0.014 m³/s·t (0.75 cfm/bu). Final moisture content seemed to be less sensitive to weather conditions at higher airflow rates.

Electrical energy consumed by the drying fan per unit of water removed from the desiccant increased as airflow rate and/or grain-mass/collector-area ratio increased. Because solar collector costs exceeded electrical energy costs, total cost to remove a unit of water from the desiccant decreased as grain-mass/collector-area ratio increased.

## RECOMMENDATIONS

Recommendations apply to corn desiccant preparation systems which start with 15% corn about May 1, which have weather conditions similar to Des Moines, Iowa, and use solar collectors with efficiency curves similar to the described collector. The recommended airflow rate and grain-mass/collector-area ratio were chosen to achieve a final corn moisture of 8 to 10%, a moisture content range that enables the desiccant system to work,

*(continued on page 194)*

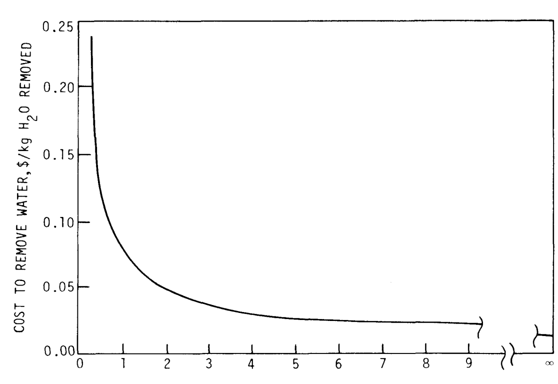


**Fig. 13—Cost to remove water vs. grain-mass/collector-area. Airflow rate: 0.014 m³/s·t (central Iowa).**