

# LOW-TEMPERATURE AND COMBINATION CORN DRYING IN ONTARIO

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The performance of a low-temperature corn-drying system was studied in 1978 and 1979. Low-temperature drying treatments involved ambient air drying of corn directly from the field, and drying of partially dried corn in a combination high-low temperature approach. One of the two low-temperature bins used in each year had a bin-wall solar collector for supplemental heating. The specific energy consumption for all four experiments was found to vary between 3.9 and 4.1 MJ/kg of water removed, which is similar to the energy use in a conventional high-temperature, continuous-flow dryer. The corn quality in the combination drying experiment is superior to that of conventionally dried corn.

## INTRODUCTION

Canadian corn producers are attempting to improve the quality of their grain to a level that is acceptable to industrial corn processors, and also to reduce their dependence on high-grade fuels (e.g. propane) normally required for drying. Low-temperature drying has the potential to meet both of these objectives.

The quality of corn dried with a low-temperature system is high if spoilage is avoided (Brown et al. 1979). The system is also less vulnerable to fluctuating supplies and prices of petroleum since electricity is the primary energy input and electrical power is abundant in Ontario.

Thompson (1972) concluded from a computer simulation study of low-temperature corn drying that deterioration of grain is doubled for each 2% increase in initial moisture content, in the range of 20-25% moisture. Shove (1976) has developed design guidelines for low-temperature corn drying in the Midwestern United States. He recommends an airflow rate of 27 L/sec.m<sup>3</sup> of grain (2 cfm/bu) for corn harvested at 24% moisture content, and 40 L/sec.m<sup>3</sup> of grain (3 cfm/bu) for an initial moisture content of 26%. Drying times at these airflow rates should be from 3 to 4 wk. During periods of adverse weather conditions, the drying air stream should be heated 2-5°C above ambient to increase its drying potential. This supplemental heat is usually provided by electric heaters; however, a solar collector with air as the heat transfer medium is an alternative energy input.

Not all researchers agree that it is necessary or even advisable to heat the drying air a few degrees. For example, Van Ee and Kline (1979) suggested that fan horse power be increased rather than adding large heating units for efficient low-temperature drying. However, simulation

studies by Mittal and Otten (1981) have shown that for Southern Ontario it is always necessary to add supplemental heat to the drying air when ambient conditions are unfavorable for drying. Failure to add heat will result in excessive dry matter losses, spoilage, or the need to finish drying in the spring.

A low-temperature system for corn harvested above 26% moisture is difficult to design due to the high airflow rate required to prevent spoilage. Unless a very shallow grain bed depth is used, a prohibitively large and expensive fan would be necessary.

Combination drying, or high-low temperature drying, offers most of the advantages of low-temperature drying to the producer who often harvests corn at a high moisture content. Wet corn is partially dried to 20-22% moisture in a high-temperature batch or continuous flow dryer. The hot, moist corn is transferred from the dryer to a low-temperature drying bin where it is slowly cooled and then dried to the desired final moisture content. Morey et al. (1978) reported that this drying method reduced the propane energy requirements for drying corn, increased the capacity of the high-temperature dryer, and decreased the total energy use for drying in most cases. The quality of corn dried with the combination system was superior to that of corn dried with a conventional high-temperature method (Gustafson et al. 1978).

Corn produced in Ontario is frequently harvested at well above 26% moisture, so a low-temperature drying system must be used in combination with a high-temperature dryer in those years when initial moisture content of corn is high. This study was initiated to compare the performance of a low-temperature corn-drying system to conventional high-temperature

drying under Ontario harvest conditions. The system was operated in two ways; alone, and in combination with a high-temperature dryer. An additional objective was to evaluate the potential of solar energy for low-temperature drying. Overall energy consumption and the quality of grain dried were of primary interest.

## EXPERIMENTAL APPARATUS AND PROCEDURE

The drying experiments were conducted at the Ontario Ministry of Agriculture and Food research farm 5 km southeast of Guelph. Harvest moisture content of early-maturing corn hybrids grown on the farm can be expected to be 25% or less by the end of October in about 40% of all harvest years. Combination drying would be necessary for the remaining years.

Two low-temperature drying bins were erected at the farm in 1978. These bins were designed to accommodate corn up to 24% initial moisture, according to the recommendations published by Shove (1976). The bins were 5.9 m in diameter and measured 6.2 m to the eave (i.e. 5000 bu capacity). Each bin had a fully perforated false floor and a 680-mm diameter, 9.3-kW axial drying fan. Although three 10-kW resistance heaters were installed in the duct between each fan and bin, only one heater was used for supplemental heating in the 1979 experiment.

A bin-wall, covered-plate solar collector extended around two-thirds of the circumference of one bin. The collector was centered over the drying fan which was on the south side of the bin. A detailed description of the collector is given by Johnson and Otten (1980).

The airflow rate in each bin was measured with a sensitive vane anemometer mounted in the neck of an amplifying cone. Two complete traverses across the

top surface of grain in each bin were made to determine the average velocity of air through the corn.

The corn in the bins was sampled while it dried by inserting a sampling probe into the grain bed through a series of ports on the north side of each bin. The sampling ports were spaced vertically at 610-mm intervals.

Electrical energy demand and usage were measured by kilowatt-hour and demand meters at each bin.

Air temperatures at various locations in the air ducts and collector were recorded at half-hour intervals. Grain temperatures were monitored daily with an array of nine thermocouples suspended at the center of each bin. Relative humidity of ambient air was recorded by two thermohygrographs, which have an accuracy of  $\pm 0.2\%$  of range.

The high-temperature dryer used was a Behlen model M-700 four-column cross-flow dryer, rated at 7.2 tonnes of dry corn per hour at 100°C drying-air temperature and 10 percentage points of moisture reduction. A lean-to building enclosed two sides and the fan end of the dryer. Ambient air was drawn to the cooling fan from a duct through the end wall. Inlet air for the drying fan, which was enclosed by the building, was a mixture of ambient air and recycled exhaust air from the cooling and drying sections. Steam exhausted from the upper part of the drying columns was allowed to escape through 300-mm-wide gaps left between the roof of the building and the sides of the dryer. The cooling fan was not used when the dryer was set up for combination drying tests. Since all of the drying air exhausted during these tests was fully saturated, the ambient air duct normally used for cooling was opened up to prevent recirculation.

Fuel consumption of the dryer was measured by an accumulating flow-meter in the supply line. Measurements of voltage and current draw at the drying and cooling fans, along with the motor manufacturer's performance data, were used to determine electrical demand.

Grain samples were collected before the cleaned corn entered the dryer and after it was dried. All of the corn samples from the high-temperature dryer and from the low-temperature bins were immediately tested for moisture content with a Burrows Model 700 digital moisture computer. The samples were sealed in polyethylene bags and later retested in an air oven at 102°C for 72 h.

The test weight was measured in accordance with procedures outlined by the Canadian Grain Commission (1977).

The percentage of broken corn and foreign material was determined by screening 500-g subsamples over a 4.8-mm (12/64-inch) corn-dockage sieve.

A breakage potential was assessed by treating 100-g subsamples of cleaned grain in a modified food blender for 15 sec. The treated samples were re-cleaned and weighed to measure the amount of kernel breakage caused by the treatment. The metal blades of the blender were replaced by a 50-mm rotor of soft plastic which rotated at 6700 rpm for the breakage tests. This test was designed to check the relative resistance to breakage of kernels subjected to physical impact, rather than to predict the extent of damage that may occur from handling the grain in an ordinary manner.

Kernel stress cracks were detected in the samples by candling 100-kernel subsamples over a fluorescent light source.

Viability of corn samples was determined by incubating 100-kernel subsamples for 5 days at 27.5°C in a germination cabinet and counting the sprouted kernels.

## Experimental Procedures

The harvest moisture content of corn in the first year of operation (1978) was low. As a result, the corn from the combine was cleaned in a rotary grain cleaner and elevated directly into the bins. The average initial moisture content of corn in the control low-temperature bin, which was filled first, was 23.9%. Corn in the solar-assisted low-temperature bin, filled 5 days later on 23 Oct., averaged 22.2% moisture. Each fan was started once there was a 0.5-m depth of grain in the bin, and ran continuously until the end of the drying period. The electric heaters were not used in 1978 because ambient air conditions were favorable for most of the season.

The moisture content of corn harvested in 1979 was about 29%, so the combination drying approach was necessary. Wet corn was cleaned and dried to 20–22% moisture in the high-temperature dryer. Since the cooling fan of the dryer was not used, the corn was discharged hot and transferred to the low-temperature bins. Sabbah et al. (1972) concluded that, when corn is tempered and slowly cooled after high-temperature drying, the amount of moisture extracted by the cooling air increases with the duration of the tempering period and is reduced when the cooling airflow rate is increased. Therefore, the drying fan on each bin in this experiment was not started until 24 h after the first load was placed in that bin. The delay allowed all of the corn to temper for at least 8 h, and the cooling airflow rate was at the minimum since the bin was full. One of the 10-kW heaters on each bin was manually switched on at 1700 h each day and off at 0800 h the following day. The fans operated continuously until drying was completed.

For the conventional high-temperature drying test, corn was completely dried and cooled in one pass through the dryer.

## RESULTS

Details of the performance of the high-temperature dryer are given in Table I. Discharge rate of grain from the dryer increased by about 25% for partial drying in the combination treatments. The initial moisture content was about 2% higher for those treatments. Of course, capacity could have been further increased by converting the dryer to all-heat for combination drying rather than simply leaving the cooling fan off.

TABLE I. PERFORMANCE OF A HIGH-TEMPERATURE DRYER IN CONVENTIONAL AND COMBINATION DRYING METHODS (1979)

	Conventional high-temperature dry and cool	Combination drying (control bin)	Combination drying (solar bin)
High-temperature drying stage:			
Inlet moisture content (% w.b.)	27.0 (1.74)‡	29.3 (0.98)	28.6 (0.47)
Outlet moisture content (% w.b.)	14.6 (1.11)	20.4 (0.56)	20.3 (0.68)
Inlet grain temperature (°C)	10	11	10
Outlet grain temperature (°C)	16	41	45
Drying-air temperature (°C)	93	98	99
Fuel consumption (m³/h)	94.1	93.5	81.3
Electrical demand (kW)	24.9	14.2	14.2
Energy consumption (MJ/h)†	3598	3537	3082
Dried grain flowrate (kg/h)	5290	6690	6470
Moisture removal rate (kg/h)	898	842	753
Specific energy consumption (kJ/kg H <sub>2</sub> O)	4010	4020	4090

†Assuming average heating value of natural gas is 37.28 MJ/m³.

‡Standard deviation.

TABLE II. LOW-TEMPERATURE DRYING PERFORMANCE

	1978 low-temperature		1979 combination	
	Control bin	Solar bin	Control bin	Solar bin
Initial amount of grain (m <sup>3</sup> )	133	144	150	156
tonne	92.8	100.9	92.8	97.6
Moisture contents (% w.b.)				
Initial	23.9 (0.52)†	22.2 (0.33)	20.4 (0.56)	20.3 (0.68)
After cooling	-	-	18.5 (1.15)	18.9 (0.99)
Final	16.6 (1.17)	16.5 (0.81)	14.9 (0.77)	14.5 (0.50)
Airflow rate, (L/sec.m <sup>3</sup> of grain (cfm/bu))	39 (3.0)	33 (2.5)	32 (2.5)	30 (2.3)
Drying time (h (days))	746 (31)	672 (28)	387 (16)	431 (18)
Total moisture removed (kg)	8124	6888	5996	6618
Energy consumption (MJ)				
Fan	31 356	28 476	16 164	18 153
Heater	-	-	7 452	8 991
Total	31 356	28 476	23 616	27 144
Specific energy consumption (kJ/kg H <sub>2</sub> O)	3860	4130	3940	4100
Overall energy consumption, (kJ/kg H <sub>2</sub> O) (high and low-temperature)	3860	4130	4110	4100

†Standard deviation.

The specific energy consumption of the dryer was 2–5% higher when used for combination drying, and the grain temperature leaving the dryer was about 35°C higher. Since there was recirculation of exhaust air during the conventional drying treatment, part of the sensible heat in the dried corn was recovered to boost efficiency. This was not the case in the combination drying treatments; however, the sensible heat was utilized for moisture removal during cooling in the low-temperature bins.

Results of low-temperature drying tests in 1978 and 1979 are summarized in Table II. In 1979, corn was dried from 29% moisture to about 20% moisture with the high-temperature dryer before it was placed in the low-temperature bins.

Ambient conditions were favorable for drying in the fall of 1978. A detailed description of the drying process obtained from daily moisture content determinations was presented by Johnson and Otten (1980). The average daily equilibrium moisture contents (EMC) of corn at the ambient and drying-air conditions were calculated with the Chung-Pfost equation (Pfost et al. 1976). The EMC values calculated for the final 20 days of drying (1–20 November 1978) are plotted in Fig. 1. The daily contribution of solar-heated air to the drying potential is evident from the deviation in EMC values between the low-temperature and solar-assisted bins. No supplemental electric heat was provided in 1978, and since the average equilibrium moisture contents calculated for

the entire drying period were 15.7% and 14.8% for the low-temperature and solar-assisted bins, respectively, no supplemental heat was required. Drying was stopped when the moisture content of the top 0.6 m of corn was below 19%, which resulted in a volume-average moisture content of about 16.5% for each bin. By that time about 40% of the corn had been rewetted after drying to below 15.5%.

The prevailing weather conditions in the following year (1979) were less suitable for ambient drying. A plot of EMC values

for the same calendar period is presented in Fig. 2. The 10-kW heater on each bin was used during the nights. Equilibrium moisture content for ambient air, with the measured 1°C temperature rise through the drying fans, averaged 16.7% over the drying period. With the addition of supplemental heat it was possible to dry corn in both bins to below 15% because dried grain was not rewetted during the night. Of course, it is neither necessary nor desirable to have a final moisture content less than 15% when the corn is marketed; while grain corn used for feed on the farm can be kept at 15–17%. The solar energy component of total drying potential was less in the second year since the EMC of the solar-heated air was generally 0.5% or less below that of the control bin.

Specific energy consumption for low-temperature drying was about the same in both years, and was slightly lower for the control bin. Supplemental heat added in the second year did not change energy consumption.

The overall energy consumption of combination high-low temperature drying was about 2.5% higher than that of conventional high-temperature drying with exhaust-air recirculation. The solar energy captured by the collector did not improve specific energy consumption of the low-temperature method, but the final moisture content of corn was lower in the solar bin.

Results of several quality tests performed on the corn before and after drying in 1979 are summarized in Table III.

The percentage by weight of cracked corn and foreign material (i.e. BCFM) in

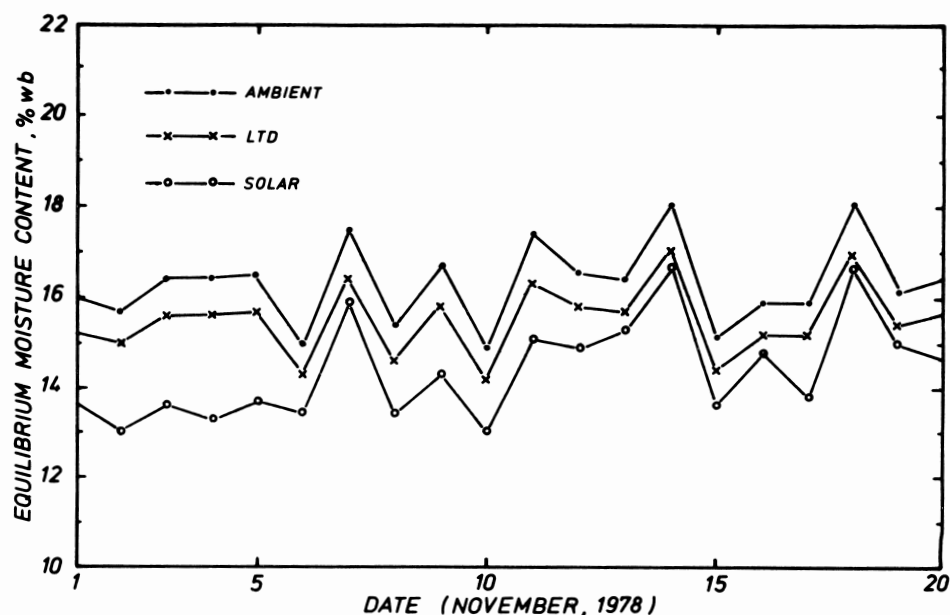


Figure 1. Equilibrium moisture content of corn for daily averaged air conditions during low-temperature drying (1978).

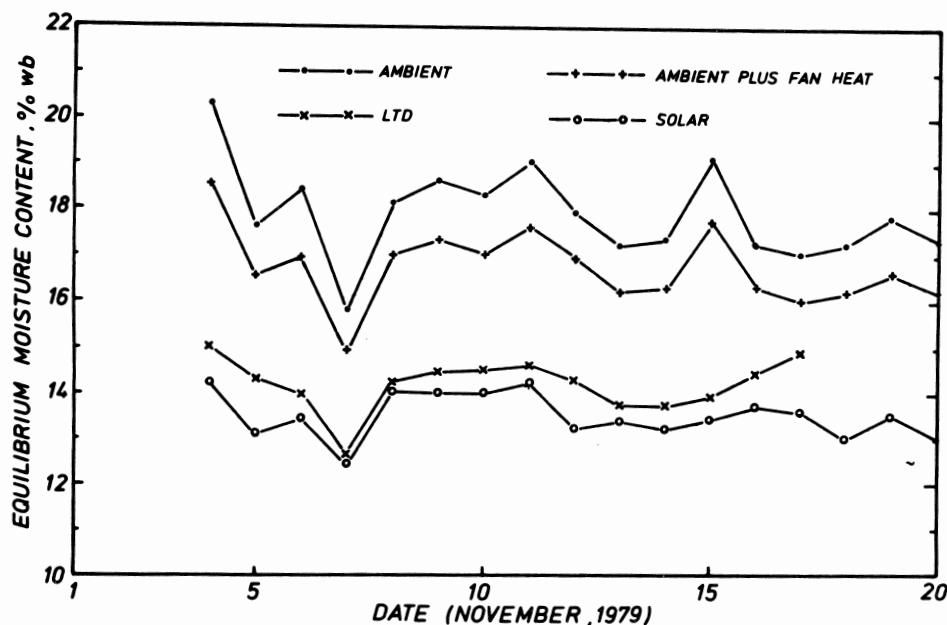


Figure 2. Equilibrium moisture content of corn for daily averaged air conditions during low-temperature drying (1979).

the wet corn was less than 1% for all three grain lots. While slightly higher after drying in all cases, the level was still well below the maximum tolerance for Grade 2 Canada Eastern Corn (Canadian Grain Commission 1977).

Test weight of corn increased substantially when it was dried. The increase in test weight of corn from the combination drying treatments was twice that of conventionally dried corn.

Viability was uniformly low for all corn due to its exposure to high-temperature drying air and the high initial moisture content before drying.

The grain that was dried conventionally had about 80% more stress-cracked kernels than that from combination treatments. Also, breakage potential, which may indicate relative susceptibility to mechanical handling damage, was almost

twice as high for conventionally dried corn as for combination treatments.

### DISCUSSION

The quality of corn dried with the combination high-low temperature method was definitely superior to that of corn from the one-pass high-temperature treatment. The improvement was in physical characteristics of the kernels (i.e., stress-cracking, bulk density, breakage susceptibility). Thompson and Foster (1963) determined that these characteristics are mainly influenced by the rate of moisture removal, and cooling rate after drying, within the critical range of moisture content from 19 to 14%.

Differences in specific energy consumption among the drying treatments were less than 5%. The specific energy consumption of 4 MJ/kg for low-temper-

ature drying and combination drying treatments in this study is high compared with results of similar experiments. Morey et al. (1978) reported that specific energy consumption for combination treatments was generally less than 3 MJ/kg. However, the airflow rate for the low-temperature stage in that study was about 13 L/sec.m<sup>3</sup> of grain (1.0 cfm/bu) and drying times ranged up to 50 days.

Supplemental heat was added in the second year (1979) to prevent rewetting during the damp nights. Specific energy consumption apparently did not change, although drying time was reduced. However, a significant amount of energy was contained in the corn as sensible heat at the start of low-temperature drying. If the cooling stage is evaluated separately from the low-temperature drying stage, specific energy consumption for low-temperature drying increased to 5660 and 5170 kJ/kg water removed for the control and solar bins, respectively. The combination of continuous fan operation with higher than necessary airflow rates and supplemental heating actually resulted in increased energy consumption.

Solar-assisted, low-temperature drying may allow grain to be dried to a lower moisture content than ambient-air drying. However, with the collector design used in this study, efficiency of drying was not improved when solar energy was applied. The cost of building and maintaining the collector was \$3.50 per tonne of grain dried annually. When this cost is added to the energy cost for drying, the solar system is about 85% more expensive than conventional low-temperature drying.

### CONCLUSIONS

The following conclusions can be drawn from the results of the drying experiments for Ontario conditions:

1. Specific energy consumption of low-temperature and combination corn drying is not significantly less than that of conventional high-temperature drying with exhaust-air recirculation.

2. The quality of corn dried with the combination method is superior to that of conventionally dried corn.

3. Supplemental solar heat slightly reduced the final moisture content of corn-dried, but did not reduce the specific energy requirement in this study. In view of the extra costs to build and maintain the collector, solar-assisted low-temperature drying was not cost-competitive with the other methods.

### ACKNOWLEDGMENTS

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TABLE III. CORN QUALITY CHANGES IN DRYING

	Conventional high-temperature drying	Combination drying (control bin)	Combination drying (solar bin)
BCFM (% by weight)			
Before drying	0.3	0.4	0.8
After drying	1.3	0.9	1.7
Test weight (kg/hL)			
Before drying	63.6	61.7	62.5
After drying	67.5	69.3	70.2
Viability after drying (%)	4.3	5.9	5.0
Stress cracks in dried corn (%)	93.3	14.4	11.1
Breakage potential (%)			
Before drying	0.3	0.7	0.8
After drying	25.3	12.1	15.5

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