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Solar Energy for Drying Shelled Corn and Hay

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Abstract

Investigations of selected types of low-cost, low-temperature rise solar collectors for drying shelled corn and chopped hay were performed in 1974 and 1975. The results indicate that bare plate, solar collectors can be an economically feasible means of providing supplemental heat for agricultural drying operations in South Dakota.

1. INTRODUCTION

Current energy shortages coupled with problems of priority use and energy distribution have increased the need for developing alternative energy sources for many agricultural applications. Use of solar energy for drying agricultural crops is limited even though much of the basic technology needed to develop these systems has been available for over ten years. Failure of agricultural producers to employ solar energy has been related in large part to the availability of conventional energy sources at reasonable prices. However, the rapidly increasing costs of fossil fuels have begun to change this situation and it is becoming important that alternate energy systems be designed that will perform satisfactorily under specified management, environmental and climatic conditions.

Many of the techniques developed through solar energy research seem to have characteristics that render them adaptable to present agricultural systems. Additional research demonstrating this compatibility is needed to encourage producers to accept and adopt solar energy for many agricultural operations. Solar drying of shelled corn and hay using low temperature air is one specific area where solar energy may be beneficial. Therefore, research to evaluate selected types of low-cost, low-temperature rise solar collectors was conducted with the following objectives:

(1) Compare the performance of selected types of solar collectors for supplemental heating of air used for drying shelled corn.
(2) Compare drying rates for shelled corn dried using selected solar collectors for providing supplemental heat.
(3) Establish the economic and energy efficiencies of drying shelled corn using solar energy as a supplemental heat source.
(4) Compare cold air and solar supplemented air for drying hay.

2. LITERATURE REVIEW

Potentially, solar energy has all the applications of conventional energy sources (6), and solar

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energy systems required to develop only small temperature differentials are relatively simple from an engineering standpoint. Unusual manufacturing techniques or exotic materials are not required to develop these small temperature differentials. For most agricultural applications satisfactory results may be obtained without high temperatures, and the energy required is small compared to the amount falling on the area required to produce the crops.

Numerous studies have indicated that solar heated air can be used for crop drying (1), (2), (3), (4), (5), (7), (8), (9), (10), (11) and (12). The predominant factor in adaption of solar energy for crop drying is that only a low-temperature rise is needed.

3. PROCEDURE

The research was conducted in three parts during the 1974 and 1975 corn and hay drying seasons in South Dakota. One was a comparison of five types of solar collectors mounted on one bin at the James Valley Research and Extension Center near Redfield, South Dakota. The second was a comparison of a solar drying bin with a conventional low temperature drying bin located near Arlington, South Dakota and the third was a comparison of cold air and solar supplemented drying of chopped hay on the Agricultural Engineering Department Research Farm near Brookings, South Dakota.

3.1 COMPARISON OF FIVE TYPES OF SOLAR COLLECTORS

Five types of solar collectors (Figure 1) were mounted on the southern two-thirds of a 14-foot diameter drying bin at the James Valley Research and Extension Center near Redfield, South Dakota. All collectors included a 3-inch air space between the bin wall and the outside surface with collectors A and B of the covered suspended-sheet type and C, D and E of the bare-corrugated sheet type. All solar absorber surfaces were painted with a commercially available flat-black enamel. An 8 kilowatt electric heater was installed downstream from the 3 hp, 18-inch diameter, tube axial drying fan. The fan operated continuously and the heater was time clock controlled to operate from midnight to 600 hours. Thermocouples were installed at the entrance and near the exit of each collector, outdoors, under the perforated floor, above the shelled corn and at the fan entrance. Temperatures were monitored every two hours with a 24-point recording potentiometer. Airflows were monitored with a hot-wire anemometer and energy inputs were measured with standard kilowatt-hour meters.

Shelled corn samples were taken from each load during filling of the bin and moisture content was measured at two-foot intervals at two locations in the bin weekly. Moisture content was determined by oven drying for 72 hours at 217 F. During the 1974 season, drying occurred from October 24 to November 5. Drying during 1975 extended from November 5 to November 25. The solar collectors were modified by inserting a 3/4" thickness of styrofoam inside of the bin wall to reduce heat transfer from within the bin to the solar collectors and by replacing Collector A (Figure 1) with a 45-degree, vee corrugated, aluminum, bare plate collector painted black, during the 1975 corn drying studies.

3.2 SOLAR VERSUS CONVENTIONAL LOW-TEMPERATURE DRYING

The solar bin was 18 feet in diameter, had a 3300-bushel capacity and was equipped with a 7-1/2 hp, 24-inch diameter fan, a 19.2 kilowatt heater and was located near Arlington, South Dakota. The solar collector was constructed around the southern two-thirds of the bin. It was of the suspended-sheet type with air flowing on both sides of a black-painted solar absorber. The absorber was used aluminum offset printing plates. A three-inch air space was provided on each side of the solar absorber and airflow was designed to have a velocity of 1500 ft/min.

The low-temperature, electric heat drying bin was located approximately 1-1/2 miles east of the solar bin. The bin was identical to the solar bin, except it did not have a solar collector. During 1974, drying with the solar bin was performed from October 12 to October 30 and drying with the low-temperature bin was conducted from October 8 to October 23. Initial and final moisture contents in the solar and conventional bins were 18.2 and 13% and 20.0 and 13.5%, respectively. In 1975 drying in the solar bin was started on October 14 and in the conventional bin it was started on October 21.

3.3 SOLAR SUPPLEMENTED HAY DRYING

Six, 2000-lb hay stacks, formed using a commercially available hay handling system were dried using cold and solar heated air provided from 8:00 a.m. to 8:00 p.m. daily. The cold air dried stacks were provided approximately 1100 cfm of air and the solar dried stacks were provided 400 cfm of air. A 100-ft^2, bare plate solar collector, constructed of plywood and blackened aluminum siding and oriented perpendicular to the incident solar radiation was used to provide the solar energy input. The hay was dried in two trials (July 31 to August 11, 1975 and September 10 to 22, 1975) from an initial moisture content of from 30 to 40% wet basis.

Insolation data were continuously monitored using an Eppley pyranometer, hay samples were taken on a daily basis during Trial 1 and on an every-other-day basis during Trial 2 and solar collector temperature data were measured using copper-constanton thermocouples and were monitored every two hours using a multi-point, strip-chart recording potentiometer.

4. RESULTS AND DISCUSSION

4.1 COMPARISONS OF FIVE TYPES OF SOLAR COLLECTORS

Average hourly quantities of energy collected along with the solar energy received on a horizontal surface are illustrated in Figure 2. These data are for a period when average outside temperature was 5.9 F above normal, average relative humidity was 3.6 percent above normal and number of possible sunshine hours was 6.3 percent below normal. The largest average hourly energy total was collected by Collector E, the galvanized bare plate collector (Figure 1).

Performance data for five days are presented in Table 1. The largest energy totals were provided by Collector E, the bare plate, corrugated, galvanized steel roofing collector. However, heat conduction from the air plenum below the perforated drying floor may have biased the data for this collector. Solar efficiency ranged from 13.5 to 90.0 percent and averaged 50.2 percent for the five days studied. Energy and economic savings of the five collectors are presented in Table 2. Largest energy savings were provided by Collectors D and E, however, as noted above the data for Collector E may be biased.

Energy collected at noon and 1600 hours are presented in Table 3 for the five types of collectors studied at Redfield, during the 1975 drying season. At noon the largest amount of energy was collected by Collector E, a bare plate unit constructed of corrugated galvanized steel roofing painted black. The covered collector (B) received the second largest amount of energy. At 1600 hours the largest energy amount was collected by Collector D, which was constructed of corrugated aluminum roofing painted black. At this time Collector E provided the least energy and Collector B the third most energy. Energy incident on a horizontal surface of equivalent area is presented as a reference value.

4.2 SOLAR VERSUS CONVENTIONAL LOW-TEMPERATURE DRYING

<u>1974 drying season</u>. Comparative performance data for the solar bin and the low-temperature bin are provided in Table 4. For this drying season, when outside temperature averaged 9.5 F higher, relative humidity 15.6 percent lower and hours of possible sunshine 22 percent higher than normal, the savings associated with use of the solar supplemented drying system was approximately 26 percent.

<u>1975 drying season</u>. Comparative performance data for the solar bin and the low-temperature bin are provided in Table 5. An energy savings of 55.5 percent was noted in comparing drying system performance during this season. However, a part of

this sizeable difference may have been caused by excess use of the electric heater on the conventional low-temperature bin.

4.5 SOLAR SUPPLEMENTED HAY DRYING

Solar collector efficiencies at 10:00 a.m. and 2:00 p.m. are illustrated in Figure 4 for Trial 1. These efficiencies are a ratio of the actual energy collected in the air stream to the solar energy incident on a horizontal plane of equivalent area. Typical efficiencies were in the range of 60 to 80% for Trial 1 but ranged from 20 to over 100% during Trial 2. Cloudy and rainy periods reduced the level of insolation on several days during Trial 2. Total energy collection on 8/6/75 was 135,000 Btu or 1351 Btu/ft^2 of solar collector. Hay drying rates for the two trials are presented in Figures 5 and 6. Drying rate data for one solar dried stack are omitted for both trials due to inadequate airflow to provide a realistic drying rate. Unequal stack densities and rainfall were additional factors that affected drying rates of the stacks.

During Trial 1 the drying rates for the solar dried stack and the cold-air dried stack were 2.67 and 2.82 percentage points of moisture per day. Therefore, the addition of the solar energy allowed an approximately equal drying rate with only one-half as large an airflow. During Trial 2 similar drying rates were also noted between the solar dried and the low-temperature dried stacks. Again a lower air flow was used with the solar dried hay.

5. CONCLUSIONS

The results of these investigations indicate the following conclusions:

(1) Black-painted bare sheet, corrugated steel collectors can be just as efficient for collecting solar energy (for small temperature rises required for low-temperature drying) as plastic-covered collectors and can be installed at a lower cost.

(2) Solar collectors, mounted on the outside of a typical, round, low-temperature drying bin, can provide an economically feasible means of supplying supplemental heat for drying shelled corn in South Dakota.

(3) Similar hay drying rates were obtained with solar dried stacks provided approximately one-half as much airflow as was noted for cold-air dried hay stacks.

(4) Bare plate solar collectors designed to provide a low-temperature rise appear to be an economically feasible alternative for drying shelled corn and chopped hay in South Dakota.

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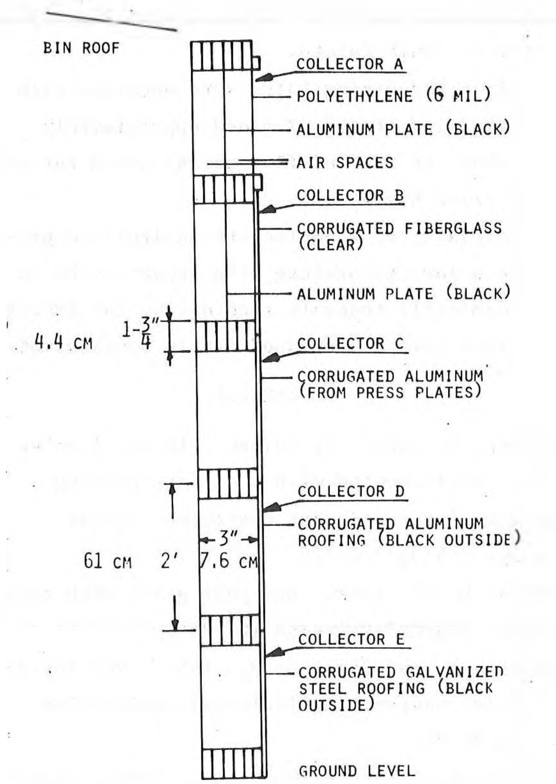

Figure 1. Collector Detail, Redfield Solar Bin.

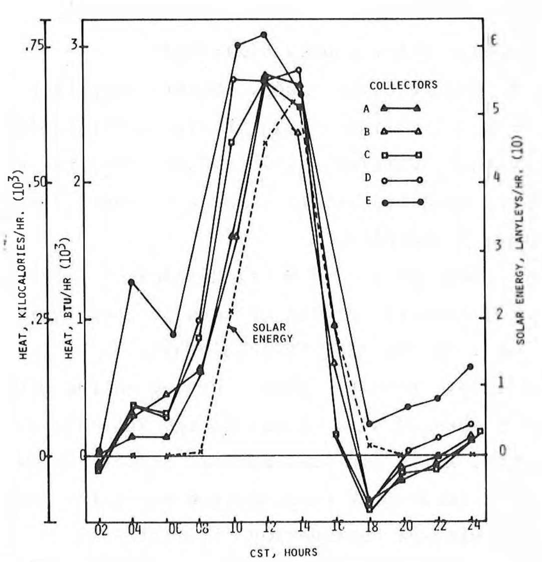

Figure 2. Average Hourly Heat Collection and Solar Energy on a Horizontal Surface. Note: Values for Collector E are distorted due to heat transfer from plenum through bin wall.

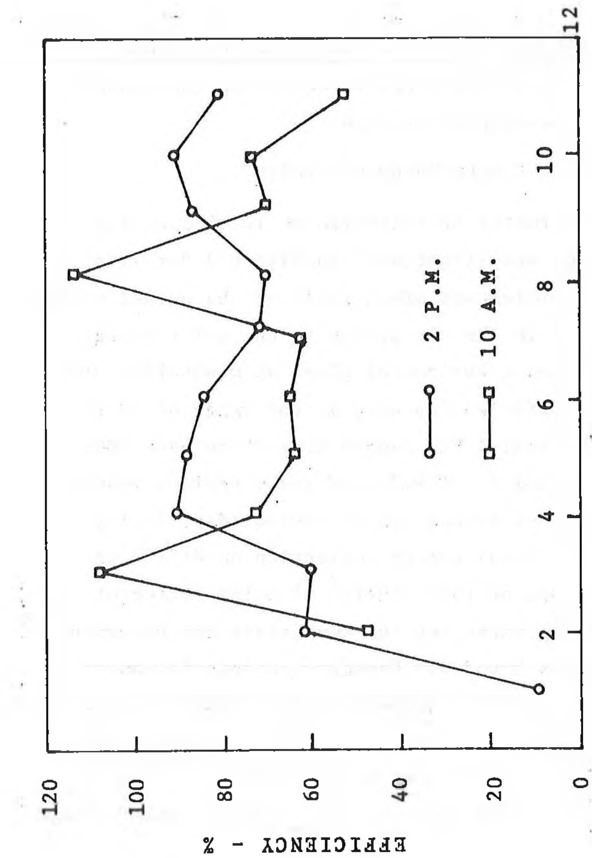

Figure 3. Solar Collector Efficiency at 10 A.M. and 2 P.M., 8/1-8/11/75.

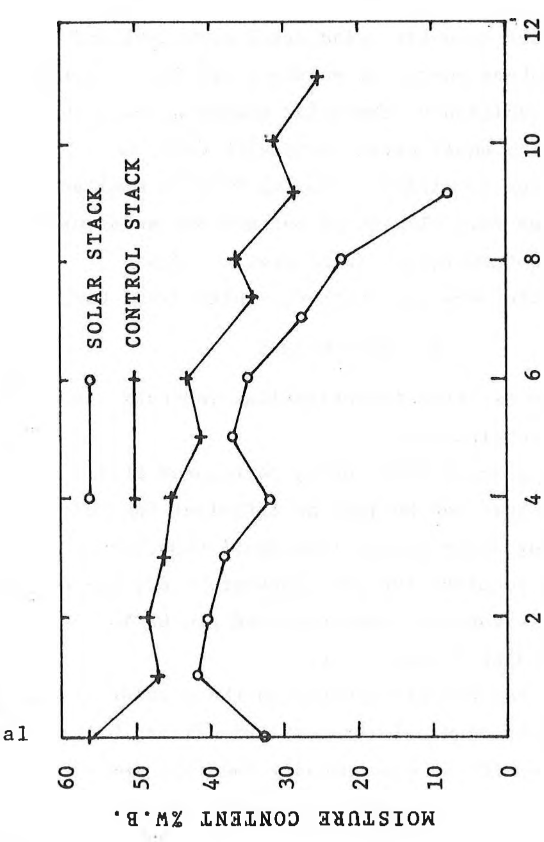

Figure 4. Hay Drying Rates, Trial 1.

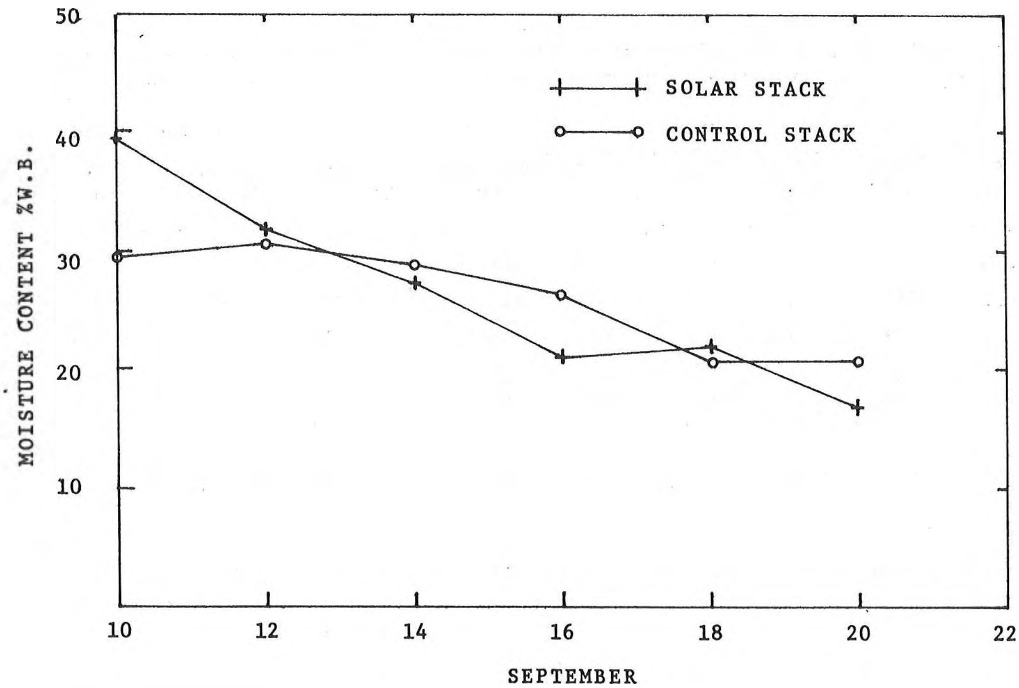

Figure 5, Hay Drying Rate, Trial 2.

Table 1. Performance Data for Five Low Temperature Rise Solar Collectors.

Date	Collector	Area ft^2	Temp. Rise ^{0}F	Solar Heat Added Max. Btu/hr	Solar Heat Added Per Day Btu	Solar Use Efficiency (Max.) %
10-26-74	A	58.6	15.4	5164	17,055	64.2
	B	58.6	10.7	3889	12,609	49.1
	C	58.6	10.5	6071	17,172	76.6
	D	58.6	8.2	5117	20,530	65.6
	E(1)	58.6	7.9	6248	20,337	78.8
10-27-74	A	58.6	15.2	5302	11,457	75.8
	B	58.6	14.3	6290	14,343	90.0
	C	58.6	8.0	4626	14,281	66.1
	D	58.6	7.9	4930	17,971	70.5
	E	58.6	6.9	5457	22,541	78.0
10-29-74	A	58.6	15.5	5282	5,557	68.7
	B	58.6	10.7	4617	5,269	60.0
	C	58.6	7.8	4509	7,632	58.6
	D	58.6	8.4	5241	8,424	68.1
	E	58.6	5.2	4113	11,310	53.5
10-30-74	A	58.6	2.4	808	3,712	31.5
	B	58.6	1.7	816	4,647	31.8
	C	58.6	1.0	578	3,932	22.5
	D	58.6	1.0	624	4,368	24.3
	E	58.6	0.6	475	7,277	18.5
11-04-74	A	58.6	2.5	820	10,602	13.5
	B	58.6	2.1	971	8,960	16.0
	C	58.6	2.6	1503	10,060	24.8
	D	58.6	2.1	1310	10,421	21.6
	E	58.6	2.0	1582	18,903	26.1

(1) Data for Collector E may be inaccurate due to heat transfer from the plenum beneath the perforated bin floor.

Table 2. Energy and Economic Savings Provided by Five Types of Low Temperature Solar Collectors.

	Actual Energy Provided						Economic Efficiency			
Collector	Kwhr Saved	Total Btu(10^3)	Period \$(1)	Avg. Btu(10^3)	Hourly \$	Avg. Max. Btu	¢ per Tot. Cost	¢ per Mtl. Cost	¢ per Total Cost/yr	¢ per Mtl. Cost/yr
A	60.0	205	1.2	8.5	.05	2168	0.96	3.0	0.5	1.5
B	56.7	193	1.13	8.0	.05	2572	0.71	1.5	0.4	0.8
C	59.3	202	1.19	8.4	.05	2339	1.15	2.8	0.2	0.6
D	63.9	237	1.39	9.8	.06	2387	1.19	2.5	0.2	0.5
E(2)	107.2	366	2.14	15.2	.09	3106	1.84	3.8	0.4	0.8

(1) 2¢/Kwhr
(2) May be inaccurate due to heat transfer from the plenum beneath the perforated bin floor.

Table 3. Energy Collected at Noon and 1600 Hours by Five Solar Collectors--Redfield, 1975 (Btu/hr)

Time	A	B	C	D	E	Solar Energy on a Horizontal Surface
Noon	4043.4	5266.1	4527.4	5253.1	6220.8	5016.4
1600	838.1	976.3	1002.2	1161.2	794.9	1192.5

Table 4. Selected Data, Solar Bin and Conventional Low-Temperature Bin, 1974

INITIAL	SOLAR BIN	CONVENTIONAL BIN
Ave. Moisture	18.16%	20.04%
October 23		
Ave. Moist. Content	12.77	13.46
Moist. Removed - Pts.	5.39	6.08
Bushels	2950 (103 cu. M)	2030 (71.4 cu. M)
KWH-Fan	1964	1844
KWH-Heater	0	233
KWH-Total	1964	2067
KWH/Bu. (35.24 1.)	0.665	1.018
KWH/Bu.-Point	0.123 (26% Less)	0.1674
BTU/lb. Water Removed	635 (352 cal/gm)	766 (431 cal/gm

Table 5. Selected Data, Solar Bin and Convention Bin, 1975.

	SOLAR BIN	CONVENTIONAL BIN
Starting Date	Oct. 14	Oct. 21
Finishing Date	Nov. 10	Nov. 17*
Initial Moisture	22.05	20.0
Final Moisture	13.6	15.78
Moisture Removed, Pts.	8.45	4.22
Bushels	3053	3053
KWH-Fan	4869	3474
KWH-Heater	0	2014
KWH-Total	4869	5488
KWH/Bu.	1.59	1.79
KWH/Bu. - Pt.	0.1887 (55.5% Less)	0.424
Elec. BTU/lb. water removed	930	2081

* Corn was not dried to desired moisture on this date, but drying was discontinued due to cold weather.

Conventional bin may have been somewhat mismanaged. i.e. The heater may have been operated at times when it wasn't needed.

BIOGRAPHY

Mylo A. Hellickson is an Associate Professor, Department of Agricultural Engineering, South Dakota State University. He received his B.S. Ag. E. and M.S. Ag. E. from North Dakota State University in 1964 and 1966 and a Ph.D. in engineering from West Virginia University in 1969. He has been the research leader in livestock environmental research since 1969 and has also been involved with agricultural energy research since 1969. His teaching duties include the agricultural structures and environment and agricultural energy areas. He has authored over 50 technical publications and he has one patent. He is a member of ASAE, ASEE, ASHRAE and several honorary societies. He is currently chairman of the North Central Region of the ASAE and was designated as an Outstanding Young Man of American in 1971 and 1976.