Low Temperature Grain Drying with Solar Heat

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ABSTRACT

LOW temperature in-storage grain drying tests were conducted to determine the effectiveness of solar energy as supplemental heat for drying. A large part of the heat required for drying is supplied by natural air. Tests were made that compared natural air drying to drying with solar heat from a collector system. Drying rate, final moisture content, electrical energy input and grain deterioration during drying were determined. Efficiency of the solar heat systems ranged from 26 to 62 percent and drying with solar heat resulted in final moisture levels up to 2 percent lower than with natural air alone.

INTRODUCTION

A diminishing supply of petroleum fuels and increased competition for petroleum products has made the conservation of energy in grain drying an important cost and management factor. Research on solar grain drying is directed toward utilization of a renewable energy source as an alternative to petroleum fuels for drying.

Solar grain drying tests at Kansas State University were initiated in 1957 by Davis, Zachariah, and Lipper (Lipper and Davis, 1959) to compare solar supplemented drying with natural air drying. In 1960 a solar collector using a clear and black polyethylene plastic was tested by drying of sorghum. The collector was modified and tested in 1961 and 1962. In 1963 a lightweight portable collapsible collector was built and tested for drying sorghum that fall and wheat the next June 1964. By using solar heated air, drying was completed in a shorter time than by natural air system and less electricity was required.

Recent research on solar drying has been summarized in the USDA Agricultural Research Service Information Bulletin 401 (Foster and Peart, 1976).

The research reported here was directed toward determining the practicality and spoilage risks of using low temperature in-storage drying with and without added solar heat. Simple low cost collectors were evaluated for performance and efficiency.

TESTS CONDUCTED

Three pairs of drying tests were conducted in the fall of 1974. Two drying bins of the same size were used to dry comparable lots of wet grain for each pair of tests. One test of each pair was conducted with solar-heated air and one with natural air. Two pairs of tests were with shelled corn and one pair with sorghum. The solar drying approach in 1974 was to use simple air inflated tubular solar collectors for direct heating of the air for drying.

Four pairs of drying tests were conducted with the 1975 fall crop—three with corn and one with sorghum. In three pairs of tests, comparisons were made between solar-heated air and natural air for in-storage drying. In the last pair, comparisons were made between drying with direct solar-heated air and drying with air from a solar collector system having a rock-bed heat storage.

The tests conducted are tabulated and further described in Table 1.

EQUIPMENT AND PROCEDURES

Four round steel drying bins equipped with steel perforated floors were used for the tests. Two of the drying bins were 4.57 m (15 ft) in diameter and were equipped with 0.56 kW (3/4 hp) vane-axial fans, 0.31 m (12 in.) in diameter, to force air through the test grain. The second pair of bins were 5.48 m (18 ft) in diameter and used 6.0 kW (8 hp) vane-axial fans to force air through the grain.

Inflatable tubular solar collectors of one general type were used for one of the bins in five of the seven pairs of tests. These collectors had a black polyethylene absorber tube about 0.86 m (34 in.) in diameter inside a transparent polyethylene tube about 0.99 m (39 in.) in diameter. This arrangement left an air space of about 0.12 m (5 in.) at the top between the black and clear plastic tubes when they were inflated and resting on the ground. The tubes were made from sheets of plastic film 0.15 mm (6 mil) thick and 30.5 m (100 ft) long. The transparent tube was made from a sheet 3.66 m (12 ft) wide, and the black tube was made from a sheet of 3.05 m (10 ft) wide. The edges of the sheets were lapped and folded to form a seam for the tube and to obtain the desired tube diameter.

A smaller, low-profile, inflated tubular collector was used on one of the smaller bins during two tests in 1975. Clear polyvinyl film, 0.51 m (20 in.) in diameter, was used to cover a black plastic absorber tube, 0.43 m (17 in.) diameter. The collector was 30.5 m (100 ft) long and is shown in Fig. 1.

For the tests in the smaller bins both the clear and black plastic tube openings were clamped to sheet metal transitions on both ends. A 0.56 kW (3/4 hp) fan forced air through the collector tubes into the solar bin and through the grain. An identical fan forced ambient air through the grain in the second bin.

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TABLE 1. DESCRIPTION OF GRAIN DRYING TESTS CONDUCTED.

Test No.	Conditions	Bin diameter Feet	Bin diameter Meters	Harvest dates	Filling depth Feet	Filling depth Meters	Average moisture content Initial Percent	Average moisture content Final Percent	Continuous fan operation Days	Airflow rates* volume air per min Ratio air vol. to grain vol.	Airflow rates* volume air per min Cfm/bu
				1974							
1	SA† corn	15	4.57	Sept. 23	4.6	1.40	22.6	13.2	20	2.04	2.54
1	NA‡ corn	15	4.57	Sept. 23	4.9	1.49	22.8	14.4	20	2.22	2.77
2	SA sorghum	15	4.57	Nov. 16	4.1	1.25	20.1	15.4	28	2.21	2.76
2	NA sorghum	15	4.57	Nov. 16	4.1	1.25	20.4	16.2	28	2.66	3.32
3	SA corn	18	5.48	Nov. 20-24	10.5	3.20	23.5	13.5	50‖	2.65	3.30
3	NA corn	18	5.48	Nov. 20-24	11.0	3.35	22.1	15.1	50‖	2.52	3.14
				1975							
4	SA sorghum	15	4.57	Sept. 17	5.5	1.68	24.3	12.1	22	1.65	2.05
4	NA sorghum	15	4.57	Sept. 17	5.5	1.68	23.6	14.2	22	1.73	2.15
5	SA corn	18	5.48	Sept. 22-24	9.8	2.99	23.8	12.0	12	3.46	4.31
5	NA corn	18	5.48	Sept. 22-24	9.7	2.96	22.0	12.3	12	3.29	4.10
6	SA corn	15	4.57	Oct. 14-15	3.7	1.13	23.6	13.5	10	3.18	3.96
6	NA corn	15	4.57	Oct. 14-15	3.6	1.10	22.9	13.8	10	3.58	4.46
7	SA corn	15	4.57	Nov. 17-18	4.5	1.37	21.8	15.7	23	2.22	2.76
7	SSA§ corn	15	4.57	Nov. 17-18	4.6	1.40	22.1	14.7	23	2.09	2.60

*Dried grain volume at moisture content of 15½ percent.
†SA = solar collector heated air
‡NA = natural air
§SSA — solar heat storage air
‖Fans were scheduled 12 h per day, 8 am to 8 pm.

The solar energy collector system for the larger 5.48 m (18 ft) diameter bin had two inflatable plastic tubular collectors placed parallel on the ground about 1.8 m (6 ft) apart and oriented in an east-west direction (Fig. 2). The inlet ends were clamped to a Y-manifold attached to an auxiliary centrifugal fan to force ambient air through the collectors and to discharge it through a manifold into the inlet of the 8 hp drying fan. About 1.18 m^3/s (2500 cfm) of ambient air passed through the collectors with the drying fan running. An identical bin and fan were used in the natural air drying test.

The third type of solar collector used was a combination collector-heat storage system with 30 t (metric ton) of fist-sized limestone rock used both as the absorber and the heat storage medium. The rock was piled over a perforated duct and against a vertical wall; the rock formed an angle of repose of 35 deg facing south. The exposed surface of the rock pile and the exposed part of the wall were painted flat black. The rock covered duct was 0.3 m (12 in.) diameter perforated corrugated metal, 6.1 m (20 ft) long, with a T-connection at its center to which was attached a solid section of duct extending to the fan located outside the collector. Framed fiberglass panels (greenhouse grade) enclosed the rock pile and served as the collector covering (Fig. 3). The panels were tilted toward the south at an angle of 40 deg above horizontal and had an area of about 29.26 m^2 (315 ft^2). One 3/4 hp fan pulled ambient air through inlet cracks 1.3 to 2 cm (1/2 to 3/4 in.) wide along the length of the framed enclosure, through the rock pile, perforated duct and then forced the air through a solid duct into the bin plenum and through the corn.

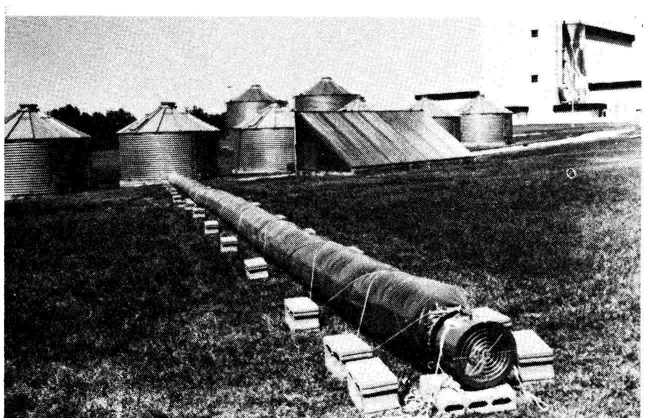

FIG. 1 Air-inflated plastic tubular solar collector used in tests 4 and 6.

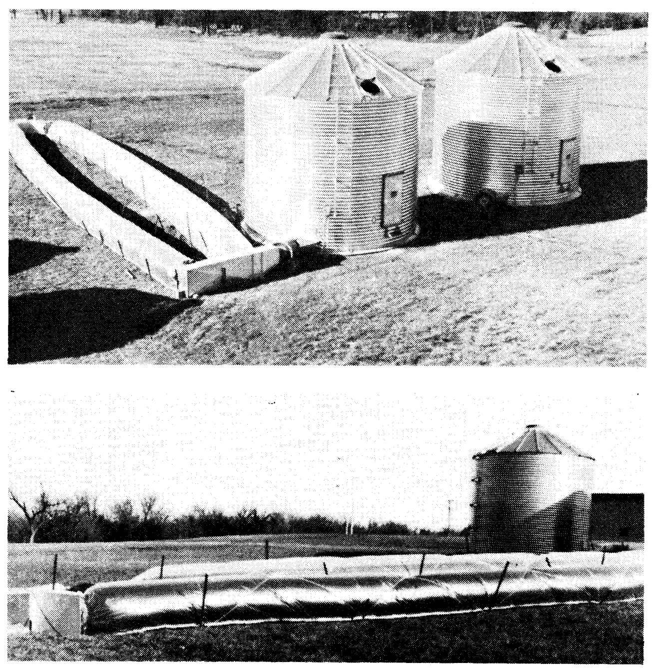

FIG. 2 Double inflated plastic tubular collector system used in tests 3 and 5.

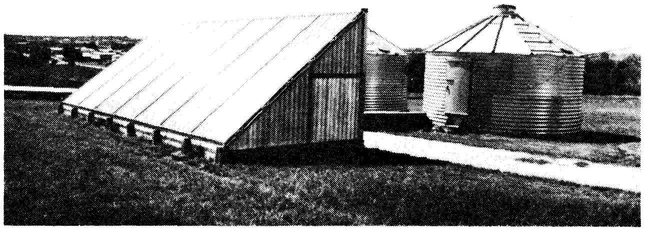

FIG. 3 Framed fiberglas panels covering rocks as a combination solar collector—thermal storage system used in test 7b.

Temperatures of the air and grain were measured with thermocouples located in the plenum under the perforated floor and at intervals through the grain depth.

The grain used in these tests was grown on local farms, harvested with a combine, and trucked to the test bins. The grain was sampled initially as each truck of wet grain was unloaded. Grade factors were determined on a representative sample from each truck. Grain moisture content was determined either by an electronic tester or by the air-oven method, or both. After the test bin was loaded and at intervals during the drying operation, samples were obtained by inserting grain probes from the grain surface to the floor.

The grain was evaluated for fungal invasion initially, at selected sampling intervals during drying, and after drying was completed. Seeds were surface-sterilized by shaking for 1 min in 2 percent NaOCl, and rinsed in sterile water. Then 100 kernels were plated on malt agar containing 4 percent NaCl and 200 ppm Tergitol NPX (Union Carbide Corp.*) to determine invasion after an incubation period.

The second year, the wet corn was run through a rotary screen grain cleaner to remove the broken corn and foreign material smaller than 0.5 cm (3/16 in.).

Test Conditions

The test conditions for the 1974 and 1975 tests are described in Table 1. Each year, the first tests were started in September and the last tests in November. The smaller bins were filled to a depth of 1.10 to 1.68 m (3.6 to 5.5 ft) and held from 18.2 to 28.0 m^3 (450 to 700 bu). The larger bins were filled to a depth of 2.96 to 3.35 m (9.7 to 11 ft) and held about 70.0 to 79.0 m^3 (2000 to 2250 bu). The air volume used ranged from a low of 1.40 m^3/m^3-min (2 cfm/bu) in test 4 with sorghum to a high of 3.06 m^3/m^3-min (4.4 cfm/bu) in test 5 with corn. Most of the grain used in the tests had an initial moisture content between 20 and 24 percent.

Climatic conditions were monitored during all drying periods. Hourly ambient air temperature and relative humidity readings were taken from hygrothermograph charts and averaged for each test period. The observed weather conditions including solar radiation data were compared to normal data for Manhattan, KS, published by the National Weather Records Center, Asheville, NC. Weather conditions during the various test periods are summarized in Table 2.

Good drying weather occurred in September and October both years. During test 1, average air temperature was 1.45 °C below normal and solar radiation about 2 percent below normal. Tests 2 and 3 were started in late November, and cold weather made drying slower. Drying in test 3 ran through December and half of January with fans operated from 8 a.m. to 8 p.m. on a daily schedule. Ambient air was 1.67 °C above mean normal temperature for the period.

Two days of wet cold weather during 1975 tests 4 and 5 contributed to a 3 to 4 °C below normal air temperature for the periods. However, solar radiation was 11 to 12 percent above normal. The temperature in test 6 was 1.0 °C below normal, but the radiation was above normal for the period. Test 7 started November 18 and ran 23 days, with 8 days of snowy, wet and cold weather. Ambient air temperature averaged 1.2 °C below normal.

*Names of commercial companies are used in this publication solely to provide specific information. Mention of them does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other firms not mentioned.

RESULTS

The results of the study are discussed under three headings: (a) The effectiveness of solar supplemented grain drying in terms of drying rate, final grain moisture content, and grain deterioration during drying; (b) the performance of simple low-cost solar collectors used, and (c) the effectiveness of solar heat utilization

TABLE 2. AMBIENT AIR CONDITIONS AND SOLAR RADIATION RECEPTION DURING THE DRYING PERIODS.

Test No.	Date started	Test period, Days	Average air temperature: Ambient °F	Ambient °C	Departure from normal °C	Average relative humidity, percent	Solar radiation: Received per day† Btu/ft²	Received per day† kJ/m²	Departure from normal, Percent
	1974								
1	Sept. 23	20	59.5	15.28	-1.45	55	1291	14661	- 1.8
2	Nov. 16	28	37.8	3.22	-0.11	70	656	7450	- 4.4
3	Nov. 25	50*	35.0	1.67	+1.67	61	668	7586	+ 2.7
	1975								
4	Sept. 17	22	57.4	14.12	-3.61	62	1476	16762	+12.7
5	Sept. 24	12	56.3	13.47	-4.22	61	1463	16615	+11.3
6	Oct. 15	10	56.8	13.74	-1.00	60	1240	14082	+ 6.9
7	Nov. 18	23	35.8	2.11	-1.22	71	696	7904	+ 1.4

*Fans operated 12 h per day, 8 a.m.
†Horizontal surface pyranometer data.

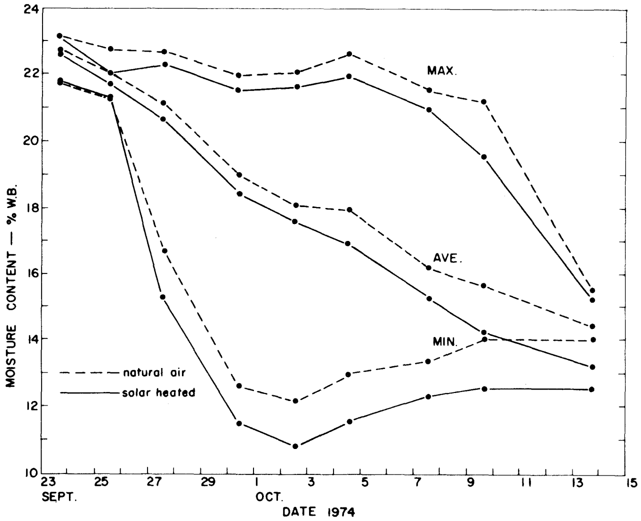

FIG. 4 Corn moisture content changes in the natural air and solar air bins—test 1.

in low temperature grain drying. The effectiveness of solar drying was judged by comparing it with natural or ambient air drying.

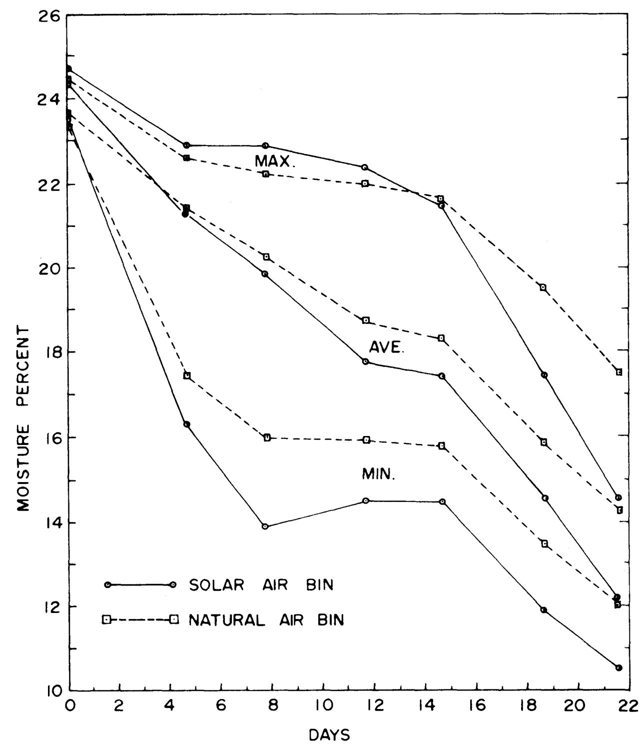

FIG. 5 Sorghum moisture content changes during test 4.

Effectiveness of Solar Grain Drying

The grain in all of the tests was dried satisfactorily by use of supplemental solar heat. In most of the tests, drying proceeded at a slightly faster rate and to a lower moisture content in the solar tests than in the natural air tests without solar heat. For example, the moisture content of the corn in the test 1 in 1974 was reduced 9.4 percentage points with solar heated air and 8.4 percentage points with natural air in 20 days drying time (Table 1).

The pattern of drying in test 1 is shown in Fig. 4. Similar data are presented graphically for 1975 sorghum drying, in Fig. 5. The average moisture content of the grain reached 15 percent in 2 to 4 days less time in the solar tests than in the natural air drying tests. Perhaps of more importance, the maximum moisture at the end of sorghum drying test (Fig. 5) was near 14.5 percent while the moisture content of the top layer of sorghum in the natural air test was still above 17 percent.

The 1975 sorghum tests had the greatest difference between the final average moisture levels, with the grain in the solar test reaching 12.1 percent when that in natural air test was 14.2 percent. In each of the tests conducted, solar dried grain reached a lower moisture content than did the grain dried by natural air; however, in half of the tests the difference was less than 1 percentage point. In test 3, started late in 1974, fan operation was confined to about 12 hr each day; fan operation was continuous in all other tests.

Grain and air temperatures measured during the tests showed that the grain temperatures tended to follow changes in air temperature. Grain near the bottom of the bin where the drying air entered followed outdoor temperatures closely, while the surface grain temperature changes lagged some 4 to 6 hr behind air temperature changes, depending on airflow rate. In sorghum test 4, the grain warmed about 10 hr and cooled about 14 hr each day. Temperatures of the top surface grain reached a minimum about noon and a maximum about 10 p.m.

There was minor grain quality deterioration indicated by mold growth in some of the tests. Deterioration was generally confined to the surface grain that was last to dry. In test 1, there was slightly more *Penicillium* growth in the solar dried grain than in that dried with natural air. Percentage of kernels invaded by *Penicillium* increased from 10 percent initially to 60 to 80 percent after 2 wk in the upper third of the grain near the center of the bin. *Aspergillus ochraceus* also appeared in moderate amounts and *Alternaria* increased somewhat, but did not reach levels considered important to the maintenance of grain quality during storage. *Penicillium* also showed up in the natural air bin in the upper layers of corn in test 3. Slight increases in *Penicillium, Cladosporium,* and *Alternaria* occurred in the top layer of the corn in solar test 6. There was no significant mold activity in either of the sorghum tests or in the other two corn drying tests.

It is likely that removing the fines from grain helps to minimize quality loss. In addition to the fines being very vulnerable to mold growth, they tend to prevent uniform airflow, resulting in a portion of the grain mass not drying properly. The mold growth observed in the top center of the solar heated bin in test 1, for example, might have been prevented or reduced if the fines had been removed from the corn. In the 1975 tests, fines were removed from the corn, and drying was more uniform.

Solar Collectors and Their Performance

The performance of three different inflated tube solar collector arrangements plus the combination solar collector-rock heat storage, is summarized in Table 3. The ratio of collection area to drying bin floor area ranged from 0.8 to 2.2. In terms of collection area per 3.52 m^3 (100 bu) of grain, the range was from 2.0 to 5.0 m^2 (21 to 54 ft^2).

The solar collection area reported in Table 3 was based on the diameter of the inflated black plastic tube and was considered equivalent to a flat-plate collector of that width and the tube length. The circular tube, properly oriented, presents about the same area to the sun regardless of the sun angle with a horizontal surface. Therefore, the solar energy measured by the solar cell pyranometer mounted horizontally was increased by the ratio of the amount falling on a horizontal surface to that on a surface normal to the sun for 40 deg north latitude and for the time of the year for the test periods (as interpreted from Table 2, Chapter 59, 1974 Edition, ASHRAE Application Volume). The factor for tests starting in September was 1.25, October, 1.50, November, 2.00, and December 2.20. Thus the radiation available was based on an equivalent flat-plate collector normal to the sun at the zenith.

The radiation available in the various tests ranged from 14,900 to 21,120 kJ/m^2-day (1312 to 1860 Btu/ft^2-day). The amount of energy collected, based on measurements of the quantity of air and the temperature rise in the air, varied more widely—from 4,131 to 12,949 kJ/m^2-day (364 to 1141 Btu/ft^2-day). For the eight solar tests, the average energy collected was 7,143 kJ/m^2-day (629 Btu/ft^2-day) or equivalent to about 0.68 gal of LPG or about 18.4 kWh of electrical energy per 9.29 m^2 (100 ft^2) of collector area.

The collector efficiency was based on the ratio of the energy collected to the solar energy incident upon the collector surface. The efficiency as calculated ranged from a low of 26.1 percent to a high of 61.8 percent in the eight solar tests.

The efficiency of the collector-heat storage unit, test 7b, was considerably higher than that of the inflated tube collector used for comparison (test 7a). How much of the difference can be attributed to the heat storage and how much to the difference in design of the collectors is not known.

The collector heat storage system shifted the period of maximum temperature rise in the drying air from day to night. The rocks were heated during the day and the heat was transferred to the drying air during the night. The maximum temperature of the air drawn through the rocks occurred about 6 p.m. and the minimum temperature about 9 a.m.

Solar Heat Utilization

The average contribution of the solar energy collected was about 20 percent of the total sensible heat available for drying. About 70 percent of the sensible heat was from the ambient air and about 10 percent from the electrical energy supplied to the fan (Table 4).

The utilization of the sensible heat in these tests was lower than expected, an average of about 30 percent. There was also a wide variation among tests, only a part of this can be accounted for adequately. However, the utilization efficiency in the solar tests was slightly above that in comparable natural air tests. This suggests

TABLE 3. SOLAR HEAT COLLECTOR SYSTEMS, CHARACTERISTICS AND PERFORMANCE.

Test	Date	Collector type	Collection area		Measured available solar radiation*	Energy collected per day		Collection efficiency
			Feet^2	Meter^2	Btu/ft^2 /day	Btu/ft^2	kJ/m^2	Percent
1	Sept. 23-Oct. 13	Inflated tube A	283	26.29	1614	490	5561	30.4
2	Nov. 16-Dec. 13	Inflated tube A	283	26.29	1312	387	4392	29.5
3	Nov. 25-Jan. 15	Two inflated tubes B	566	52.58	1469	533	6049	36.3
4	Sept. 17-Oct. 9	Inflated tube C	142	13.19	1845	1141	12949	61.8
5	Sept. 24-Oct. 6	Two inflated tubes B	566	52.58	1828	598	6787	32.7
6	Oct. 15-Oct. 24	Inflated tube C	142	13.19	1860	877	9953	47.1
7a	Nov. 18-Dec. 11	Inflated tube B	283	26.29	1392	364	4131	26.1
7b	Nov. 18-Dec. 11	Flat plate + rock heat storage	315	29.26	1392	641	7272	46.0

*Calculated on the basis of an equivalent flat plate collector tilted optimally toward the sun.

TABLE 4. AVERAGE DRYING AIR TEMPERATURE RISE ABOVE DEW POINT AND SENSIBLE HEAT UTILIZATION IN THE SOLAR AND NATURAL GRAIN DRYING TESTS.

Test no.	Temperature rise above dew point from, °C			Source of sensible heat from, percent			Total sensible heat utilization, percent
	Ambient	Fan	Solar	Ambient	Fan	Solar	
1 SA corn	9.39	0.78	1.94	77.5	6.4	16.1	25.2
1 NA corn	9.39	0.78	—	92.3	7.7	—	25.0
2 SA sorghum	4.89	0.78	1.56	67.7	10.8	21.5	13.8
2 NA sorghum	4.89	0.78	—	86.3	13.7	—	13.1
3 SA corn	6.17	1.44	1.89	64.9	15.2	19.9	20.2
3 NA corn	6.17	1.44	—	81.0	19.0	—	18.7
4 SA sorghum	6.78	0.94	2.54	66.0	9.2	24.8	46.6
4 NA sorghum	6.78	0.94	—	87.8	12.2	—	45.4
5 SA corn	7.44	1.50	0.94	75.3	15.1	9.6	37.3
5 NA corn	7.44	1.50	—	83.2	16.8	—	34.9
6 SA corn	7.61	0.67	1.49	77.9	6.8	15.3	46.6
6 NA corn	7.61	0.67	—	91.9	8.1	—	43.6
7 SA corn	4.50	0.83	1.22	68.6	12.7	18.7	22.1
7 SSA corn	4.50	0.83	2.50	57.4	10.7	31.9	23.2

TABLE 5. ELECTRIC ENERGY INPUT FOR DRYING TEST PERIODS COMPARING SOLAR HEATED AIR RESULTS WITH NATURAL AIR DRYING.

Test no.	Operation time, h	Grain depth, m	Rated fan motors, hp	Moisture removed total		Electric energy input to motors			
				lb	kg	Power, W	Energy, MJ	Per unit, Wh/lb	water removed, kJ/kg
1 SA corn	480	1.40	3/4	3961	1797	791	1366.8	95.8	760.7
1 NA corn	480	1.49	3/4	3842	1743	792	1368.6	98.9	785.2
2 SA sorghum	672	1.25	3/4	1754	796	803	1942.6	307.6	2440.5
2 NA sorghum	672	1.25	3/4	1567	711	803	1942.6	344.4	2732.2
3 SA corn	600	3.20	9	13958	6331	6831	14755.0	293.6	2330.5
3 NA corn	600	3.35	8	10455	4742	5933	12815.3	340.5	2702.3
4 SA sorghum	518	1.68	3/4	5960	2703	780	1454.5	67.8	538.0
4 NA sorghum	518	1.68	3/4	4740	2150	790	1473.2	86.3	685.2
5 SA corn	295	2.99	9	14762	6696	7460	7922.5	149.1	1183.2
5 NA corn	295	2.96	8	12078	5478	6340	6733.1	154.9	1229.0
6 SA corn	228	1.13	3/4	3285	1490	681	559.0	47.3	375.1
6 NA corn	228	1.10	3/4	2855	1295	746	612.3	59.6	472.8
7 SA corn	550	1.37	3/4	2540	1152	690	1366.2	149.4	1185.8
7 SSA corn	550	1.40	3/4	3060	1388	692	1370.2	124.4	987.2

that the additional solar heat added during sunny periods was utilized as effectively as the sensible heat in the natural air.

The effectiveness of supplemental solar heat can also be assessed in terms of savings in other forms of energy; electricity for fan operation in these tests, for example. While the rate of drying in low temperature in-storage drying systems is largely a function of airflow rate, there are times when weather conditions will not permit the grain to be dried to moisture levels safe for storage without supplemental heat. In this case, the addition of solar energy will reduce the length of the drying period and save considerable fan energy. On the other hand, some energy is required to inflate the plastic collectors and to overcome the friction of moving the air through any type of collector system.

An analysis of electrical energy input to the various tests, solar and natural air is given in Table 5. The results are presented on the basis of the amount of energy required to remove a unit of water from the grain. As expected, the depth and kind of grain had a direct effect on energy requirements as well as the airflow rate used. Tests with corn depths of around 3.05 m (10 ft) required up to 3 to 4 times the energy per unit of water removed as did tests with corn depths of 1.22 to 1.52 m (4 to 5 ft). Part of the added energy required was a result of the higher airflow rates used in the tests with the greater grain depths. The final moisture level achieved also affected drying efficiency, and those tests in which drying proceeded to lower moistures could be expected to require more energy.

The comparisons of energy requirements between the solar and natural air tests are important. In each case where direct comparisons were made, less electric energy was required to dry grain with solar heated air than with natural air (Table 5). The electric energy used in the solar tests was from 3 to 21 percent less than in the natural air tests. This occurred even though (a) the grain in the solar tests was dried to a lower moisture level and (b) some additional fan energy was required to overcome the resistance of the solar collectors.

While the savings in fan energy were relatively small, it should be emphasized that weather conditions at the test location were favorable for drying grain with natural air, especially in the 1975 season. The final moisture of the grain in the natural air tests was at a storable level except for sorghum test 2 and corn test 3. In these two cases, additional drying and fan energy would have been required for safe warm-weather storage of the grain.

CONCLUSIONS

In-bin grain drying systems with solar heat reduced electrical energy required to dry wet harvested sorghum and shelled corn. Drying rate was most dependent on airflow rate; however, solar heat increased the drying during each test period. Solar heat was more effective during cold and wet weather conditions.

Grain deterioration was confined to the upper grain layers, last to dry, and mainly in areas of reduced airflow rate due to fine-material in the grain. Airflow rates were more important than solar heat in differences in grain deterioration.

All of the solar heat tests demonstrated a faster drying rate when compared to the natural air tests. The surface grain in the solar heat added bin reached a favorable storage moisture content before the natural air dried bin.

During the early season and warm weather test periods, more drying than necessary occurred in the bottom-lower half of the bins receiving the solar heat. The 11 to 12 percent moisture content grain was good for transfer to long-term storage.

All three inflated tube type solar collectors performed well. Collection efficiency was largely dependent upon airflow velocity across the absorber surface. The circular tube oriented on an east-west line was better than a north-south line. The clear plastic tube made an insulating air space over the black absorber tube, and increased the heat output about 50 percent.

More fan heat was utilized with the drying air drawn through the rigid frame type solar collector than with the inflated tube type collector. The collector heat storage in rock unit was more efficient in cold weather.

References

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2 Lipper, R. I., and C. P. Davis, Jr. 1959. Solar energy for crop conditioning. ASAE Paper No. 59-902. ASAE, St. Joseph, MI 49085.