Solar Hay Drying Research At The University Of Saskatchewan

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Abstract

A new solar hay dryer was designed and developed at the University of Saskatchewan for the commercial production of high-quality hay and processed forage products. The solar hay dryer, consisting of a solar collector with aluminium absorber plate and spaced fins, a drying shed with perforated metal grate floor above the ground level, swing-away plywood frames and polyethylene curtains for effective sealing of the sides and end of the hay stack during drying, an insulated duct and a crawl space below the floor where a 3-hp In-line centrifugal fan is situated for negative pressure air circulation, was evaluated for its functional performance.

The solar collector performed satisfactorily with high average daily collector efficiency of 76% under bright sunshine conditions. Sealing the hay stack with polyethylene curtains coupled with the suction pressure produced uniform air distribution and uniform drying of the hay. The overall system drying efficiency of 79% was obtained for the drying system. The fan supplied about 70 m^3/min of air, and the air temperature rise above ambient **was** 13-l 5 °C during peak bright sunshine hours in August and 10- 13 °C in September.

In late August and early September, 1996, the solar hay dryer was used to dry hay from an average initial moisture content of 33% w.b. to 13% w.b. and from 25% w.b. to 11% w.b. in 4 and 3 days, respectively

Introduction

Field hay drying or curing, which usually leads to various levels of quality and dry matter losses due to the effect of weather, is generally practiced in the prairies and other parts of Canada. Problems associated with field hay drying are loss of digestible carbohydrates due to respiration of the active living cells and loss of protein due to heat or mold. Prolonged drying leads to the photochemical breakdown of carotene, leaf shattering and loss soluble vitamins (Moser, 1980). The hay dries slowly on the field and this usually leads to the loss of green color and the subsequent loss of quality and premium.

Hay must be dried from 70 - 80% w.b. initial moisture content at harvest to 12 - 18% w.b. moisture for safe storage in the form of bales, chopped hay or silage, and to as low as 9 - 12% w.b. moisture for further processing into pellets, cubes and wafers (ACAE, 1986; Arinze et al., 1996). Utilizing an artificial drying system can reduce the quality and nutrient losses, and preserve the integrity of the hay. The artificially dried hay would increase the productivity and the health of the animals. With the present high fuel prices and the declining petroleum reserves, using the conventional energy source could increase the cost of drying.

Solar energy can be a cost-effective means of providing energy for the drying needs on the farms. Solar energy is practical for hay and grain drying because it is well suited to in-storage type of drying which is popular in the prairies. Solar energy availability during the harvest period for hay and grain (June to October) is usually more than adequate to provide the required conditions for effective supplemental heat or heated crop drying on the prairies.

The objectives of this project were to design and develop an effective, efficient solar hay dryer for commercial production of high-quality baled hay and processed forage products, and to evaluate the functional performance of the solar hay dryer.

Design and Operational Features

As illustrated in Plate 1 and Figure 1, the solar hay dryer consists of (I) a 2.4 m x 9.1 m solar collector with ultra-violet resistant transparent fiberglass top cover and aluminium absorber plate and spaced fins painted with selective coating for maximum solar energy absorption; (ii) a 6 m long, 5 m wide and 3 m high drying bin or shed with inside perforated catwalk metal grate floor above the ground level on which bales are stacked up to 2 m high for drying, plywood wall at the inlet end of the bin to hold the bale stack, swing-away plying frames forming the top plenum for the hay stack, and polyethylene sheets attached to the frames on both sides and outlet or exhaust end of the bin for effectively sealing the hay stack during drying; (iii) an insulated duct that connects the solar collector outlet and the drying bin inlet, and a crawl space below the floor at ground level where a 3-hp In-line centrifugal fan is situated outside the crawl space for air circulation by negative pressure through the system

The fan is provided with a damper at the inlet for controlling airflow rate. In operation, the fan draws air through the solar collector where the air is heated. The fan is controlled by humidistat set at 80% relative humidity, and it is operated day and night. Polyethylene curtains were used in conjunction with negative pressure to seal the sides and one end of the hay stack leading to one-dimensional air movement shown in Figure 2. This was done to provide uniform air distribution so as to achieve uniform hay drying conditions. In order to maximize the solar energy collection, the solar collector was tilted at 45” to the horizontal.

Measurements and Performance Evaluation

Measurements

To determine the functional performance of the solar dryer, temperatures, humidities, moisture contents, air velocities, solar radiation on the collector surface and on the horizontal surface, wind speed, mass and density of hay baled samples were measured in the late summer of 1996. Dry-bulb temperatures were measured with type T thermocouples. A hygrometer with a type T thermocouples was used to measure the dry-bulb and wet-bulb temperatures at selected locations in the dryer. Air velocities were measured by a turbine placed in the insulated duct. Two pyranometers were used to measure the solar radiation incident on the collector surface and the horizontal. A Campbell Weather Station mounted outside the drying shed was used to measure the horizontal radiation, outdoor temperature, relative humidity and wind speed.

Wet and dried hay samples were collected and their moisture contents determined using the standard oven method. At least 30 randomly selected bales were weighed before and after drying, and their dimensions were also measured to determine the bulk and dry matter densities of the bales. These bales were marked and placed at different locations, top, bottom and middle, during the stacking operation.

To monitor the variation of temperature within the stack, the stack was divided into 4 sections at 1 m intervals from the inlet stack wall. Temperatures at the top, middle and bottom layers of each were measured. The thermocouple sensors were inserted about 12.5 mm into the top and bottom bales of each section. Bamboo sticks were used to insert the sensors in the middle locations.

Performance Evaluation

The thermal performance, Ec, of the solar collector was obtained by using the following equation:

$$E_c = \frac{M_a C_{pa} DT x 100}{A_c I_T} \qquad (1)$$

where M_a is the mass flowrate of air (kg/h), C_{pa} is the specific heat of air (J/kg°C), DT is the collector air temperature rise above ambient air temperature (°C), IT is the total solar radiation incident on the collector surface (kJ/hm^2), and A_c is the area of the collector.

The system drying efficiency is a measure of the overall effectiveness of a drying system, and it is the ratio of energy required to evaporate moisture from the product to the energy supplied to the dryer. The system efficiency was determined from the equation below:

$$E_d = \frac{WM x h_{fg} x100}{(A_c I_T t) + Q_F} \qquad (2)$$

where E_d is the system efficiency (%), h_{fg} is the latent heat of evaporation of water (kJ/kg), t is the time taken to evaporate WM kilograms of water (h), and Q_F is the fan energy delivered to the dryer in time t (kJ).

Results and Discussion

Figures 3a and 3b show typical solar radiation and temperature data for the dryer when 160 bales of hay were dried from 33% w.b. initial average moisture content to 13% w.b. average moisture content in four days with 1.17 m3/s airflow, damper fully opened, from noon hour of August 30, 1996 to just after mid-night September 1, 1996. Figure 3a shows that the solar radiation incident on the collector surface was higher than the solar radiation incident on the horizontal during the day when the sun was shining. The collector outlet temperature was higher during the day compared to the collector inlet and drying exhaust air temperatures. The collector inlet, collector outlet and the exhaust air temperatures were almost the same during the night.

For the first two days, the highest insolation on the collector surface was 1020 W/m^2 with a corresponding value of 752 W/m^2 on the horizontal surface indicating the tilting effect of the solar collector. Figure 3c shows the collector useful energy output and efficiency. The useful energy output and efficiency were high during the day and dropping to zero during the night. The maximum collector air temperature rise above ambient air temperature was 15 °C, and the average daily collector temperature rise was 11 °C. The maximum collector efficiency was 87% with a daily average value of 76%.

Figure 4 shows the temperature distribution from top to bottom layers of the stack. The variation of temperature as drying was taken place was indicated by the difference between the stack inlet temperature and the stack outlet temperature, which ranged from 7-l 6 °C during the day. The temperature variation was also indicated by the difference between top bale and bottom bale temperatures. There was a negligible temperature difference for temperatures measured at different locations inside the bales on top, middle and bottom of the stack. This showed that there was a uniform temperature distribution at any given height of the stack.

The effectiveness of the drying air is indicated by the difference in humidity ratio of the stack inlet and outlet air as indicated in Figure 5. The saturation humidity ratio at the stack exhaust air temperatures is also indicated in Figure 5. During the day, the exhaust humidity ratio was about 10% lower than saturation levels, indicating an effective drying process under the stated conditions. The drying rate of the stacked bales of hay obtained from the measured humidity ratio and airflow is shown in Figure 5. Average daytime drying rate was 90 kg/h, and 35 kg/h for the night-time period. The drying rate decreased with decreasing drying air temperature and product moisture.

Another batch of hay was successfully dried from 25% w.b. to 11% w.b. moisture from September 10 to 13, 1996. The sunshine was bright during the first two days and it was cloudy on the third day. The air temperature rise above ambient was 1 O-l 3 °C during peak sunshine hours and 5 °C under cloudy weather conditions. The dried samples showed an attractive green color and the leaves were still attached to the stems.

Conclusion

The solar collector performed satisfactorily with high average daily collector efficiency of 76% under bright sunshine conditions. Sealing the hay stack with polyethylene curtains coupled with the suction pressure produced uniform air distribution and uniform drying of the hay. The overall system drying efficiency of 79% was obtained for the drying system

The solar dryer was able to dry hay from an average initial moisture content of 33% w.b. to 13% w.b. and from 25% w.b. to 11% w.b. in 4 and 3 days, respectively

References

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Acknowledgments

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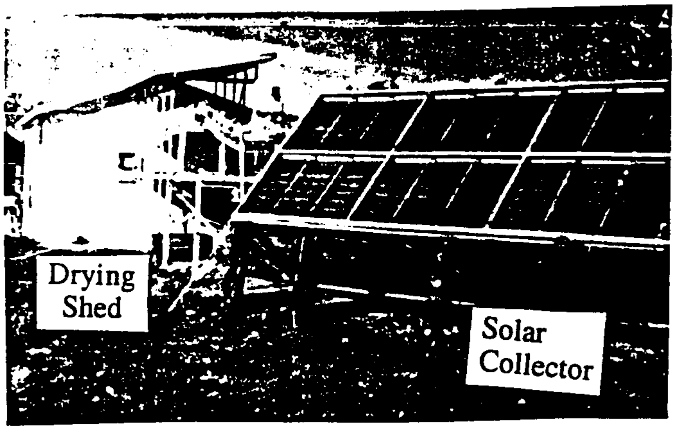

Plate 1 Pictorial view of the solar hay dryer located at the University of Saskatchewan, Saskatoon.

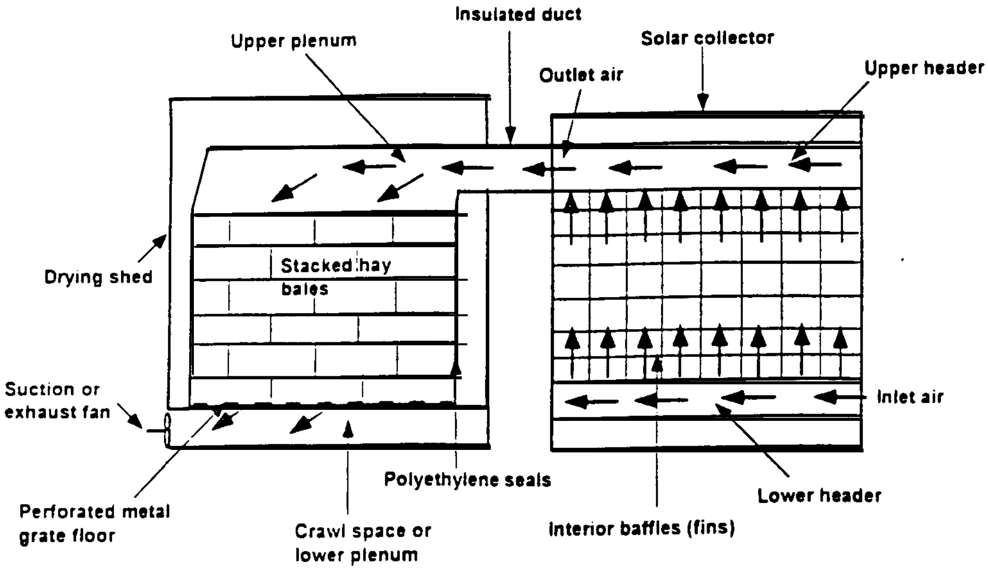

Figure 1. Schematic diagram of the solar hay dryer

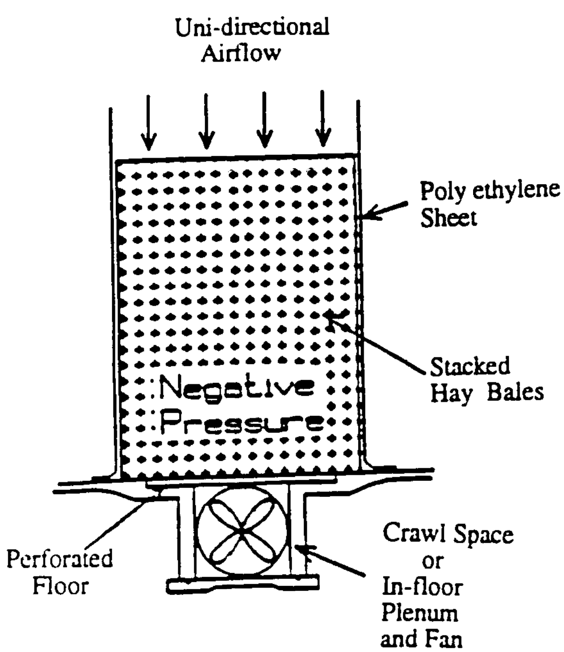

Fig. 2 Creating one-dimensional uniform airflow for the hay stack

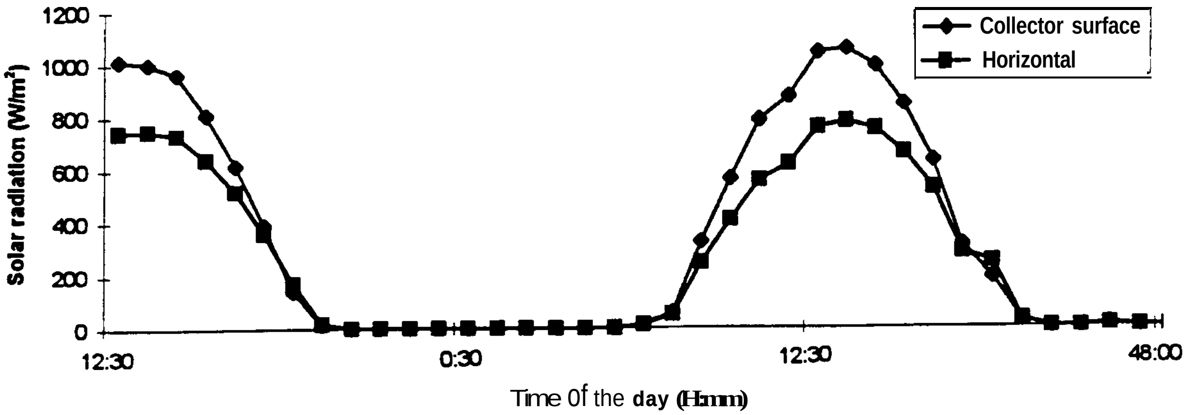

Fig. 3a. Solar radiation incident on the horizontal and collector surfaces during the hay drying operation from 12:30 p.m. August 30 to 0:30 a.m. September 1, 1996.

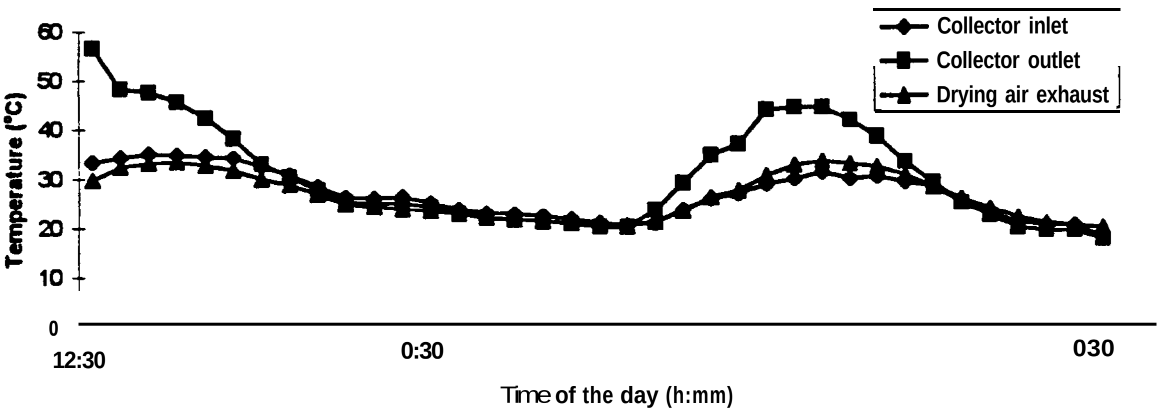

Fig. 3b. Collector inlet, collector outlet and stack outlet or drying air exhaust temperatures during the hay drying operation from 12:30 p.m. August 30 to 0:30 a.m. September 1,1996.

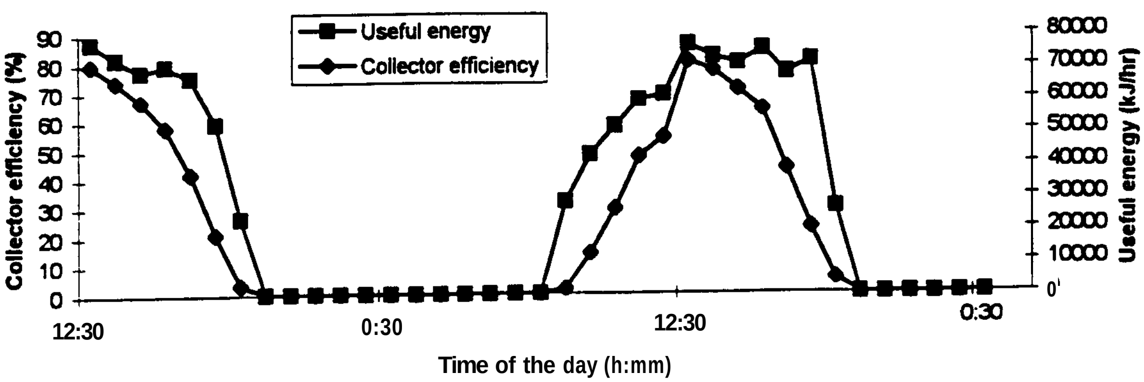

Fig. 3C. Collector useful energy gain and efficiency during the hay drying operation from 12:30 p.m. August 30 to 0:30 a.m. September 1,1996.

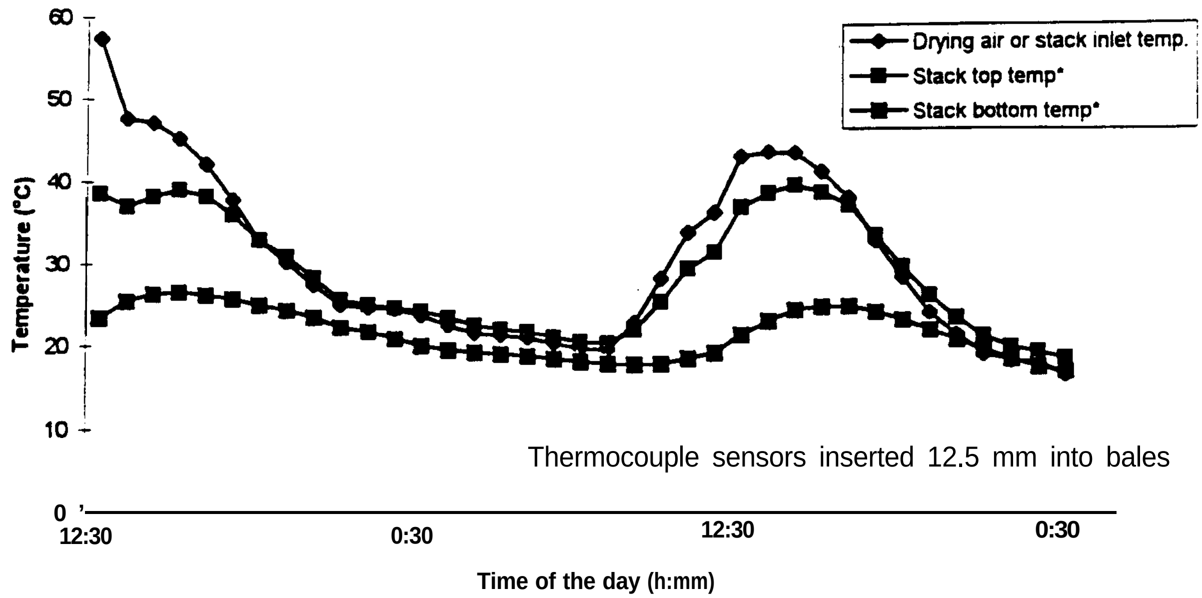

Fig. 4. **Hourly temperature distribution within the hay stack measured 2 m from the stack inlet wall or at the middle of the stack from 12:30 p.m. August 30 to 0:30 a.m. September 1, 1996 when a stack of 160 bales of hay at 33% initial average moisture content was dried with the solar dryer.**

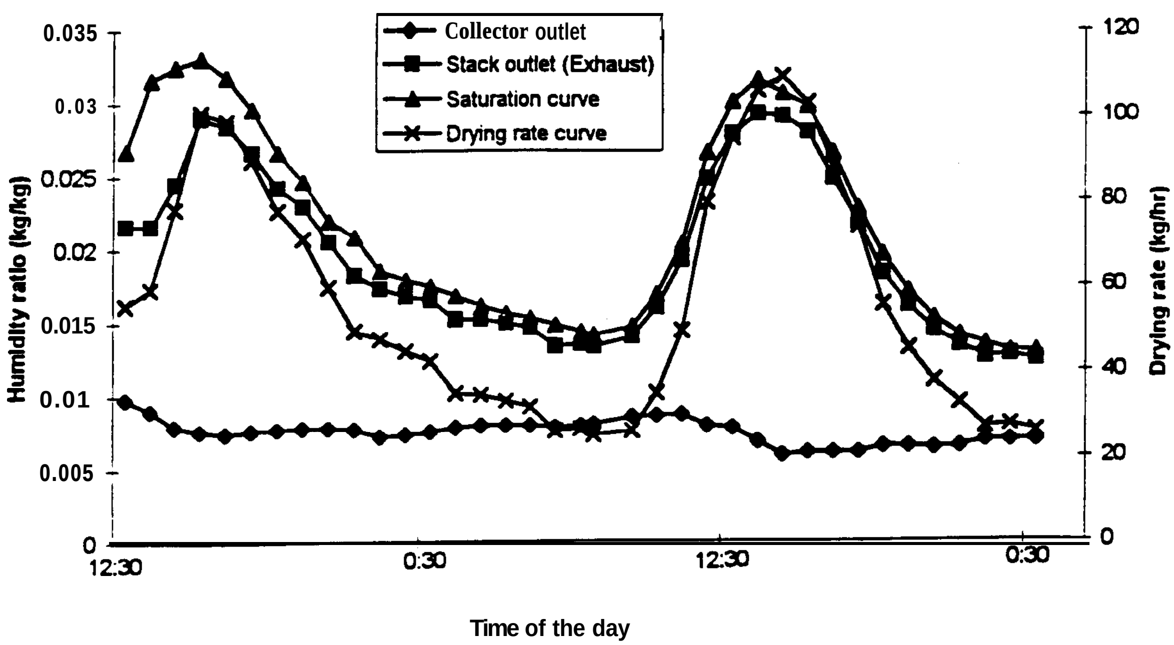

Fig. 5. Drying rate and humidity ratio (absolute humidity) vs time of the day from 12:30 p.m. August 30 to 0:30 a.m. September when a stack of 160 bales of hay at 33% initial average moisture content was dried with the solar dryer.