Performance Evaluation of a Solar Banana Dryer

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ABSTRACT

The performance of a mixed mode solar banana dryer consisting of a drying cabinet covered by 12 m² of transparent glass and 31.7 m² of flat plate solar air heater was evaluated. In operation, warm air was drawn by a fan from the solar collector and was blown through a heat exchanger before entering the drying cabinet where solar radiation was absorbed by the drying product.

Experimental results showed that the first law efficiency of the solar dryer was linearly proportional to the moisture content and dry mass of bananas per unit solar receiving area. The maximum efficiency was about 30% and occurred at an average moisture content of about 220% dry-basis and a dry mass of bananas of 3.7 kg/m² of solar receiving area. Drying time for each batch was 7 days (6 hours/day). From the financial analysis, it was found that pay-back period varied from 1.5-5.4 years when the difference in price between direct sun drying and cabinet drying varied from US$0.28 - US$0.08 per kilogram of bananas.

INTRODUCTION

Direct sun drying of local bananas is usually practiced in Thailand. The product, however, may be unhygienic due to contamination by flies and microorganisms. To improve the quality, the product should be dried in a cabinet. Solar drying in a solar cabinet dryer is a suitable alternative.

Wibulswas et al. (1977) found that the drying rate of wet cloth in a natural convection solar cabinet dryer was about 4.2 kg/m²-day. Watabutr (1981) found that the maximum drying efficiency occurred when the ratio of outlet area to solar receiving area was 0.11 (the inlet area was much larger than the outlet area) and the slope of the glass cover was 14 degrees, yielding a drying rate of about 3.2 kg/m²-day. Drying of bananas in a solar cabinet took three days and product quality was better when compared with direct sun drying (Anon, 1979).

Wibulswas and Thaina (1980) tested a mixed mode natural convection solar dryer and found that the drying rate of wet cloth was 5 kg/m²-day. Exell (1979) developed a low cost mixed mode natural convection solar dryer for paddy drying. Paddy could be dried safely in 2-3 days. Later on, research and development work on pilot scale forced convection solar drying was conducted in Thailand. Most of the work concerned grain drying especially paddy, viz., Thongprasert et al.

(1985); Soponronnarit et al. (1986); Soponronnarit and Tiansuwan (1984a) and Soponronnarit and Tiansuwan (1984b). Tobacco curing using solar energy was studied by Boonlong et al. (1984). Multiutilization of a tobacco curing barn for drying other products such as fruit was investigated by Sitthipong et al. (1987). More details are available in a review paper of Soponronnarit (1988). In addition, Ong (1986) summarized research and development work on solar drying in ASEAN countries.

From previous work conducted in Thailand, it may be concluded that natural convection solar drying of local bananas was found to be feasible (Patranon, 1984). However, little work on forced convection has been conducted. The latter may be more appropriate for use in small scale industry because it can operate simply with other sources of energy and with higher air flow rate and thus yields higher drying rate and higher system efficiency.

The objectives of this study were to evaluate the performance of a pilot scale forced convection solar dryer and to develop an empirically based mathematical model for the prediction of system efficiency. Local bananas were selected and tested in Pitsanuloke province, Thailand.

PROCEDURE

Description of Solar Dryer

The experimental solar dryer was constructed by the Physics Department, Faculty of Science, Naresuan University based on the design work of Naresuan University and King Mongkut's Institute of Technology Thonburi (Rakwichian and Soponronnarit, 1989). It consisted of a 6 x 6 m^2 flat plate solar air heater having 31.7 m^2 of solar receiving area (Fig. 1), a 2.4 m x 6 m x 1.7 m cabinet dryer having 12 m^2 of solar receiving area in which six levels of bamboo matting were placed (Fig. 2) and a supplemental heat source with heat exchanger. In operation, warm air was drawn from the solar air heater by a 1 kW centrifugal fan and blown through a shell and tube heat exchanger where heat from flue gas was transferred to the warm air before entering into the bottom of the cabinet. It then passed over the trays and finally exited at the top of the dryer (Fig. 3). Fresh air may also be drawn in to mix with warm air from the solar air heater. In this study, LPG was used in some tests as a supplemental source of heat.

Details of Experiments

Ripe bananas were peeled and placed on bamboo matting and loaded into the cabinet in the morning for drying. In the evening, the bananas were collected in bulk and covered with clean cloth for moisture redistribution in each banana fruit. The bananas were returned to the cabinet again the next morning and the process was continued for 4-6 days. Then the bananas were flattened and redried for 1-2 more days.

Air flow rate was obtained by measuring air velocity in a duct by a pitot-static tube once per day. Air temperature was measured each hour by a mercury column thermometer with an accuracy of $\pm$ 0.5°C. Relative humidity was obtained from dry and wet bulb temperatures. Solar radiation was measured by a pyranometer connected with a data logger. Loss of mass of water from drying bananas was measured at the beginning and at the end of the day by a balance having an accuracy of $\pm$ 0.5 kg. To determine the moisture content of the bananas, a sample was dried in an air oven at 103°C for 72 hours. Electricity consumed by a motor for driving the fan was measured by a watt-hour meter.

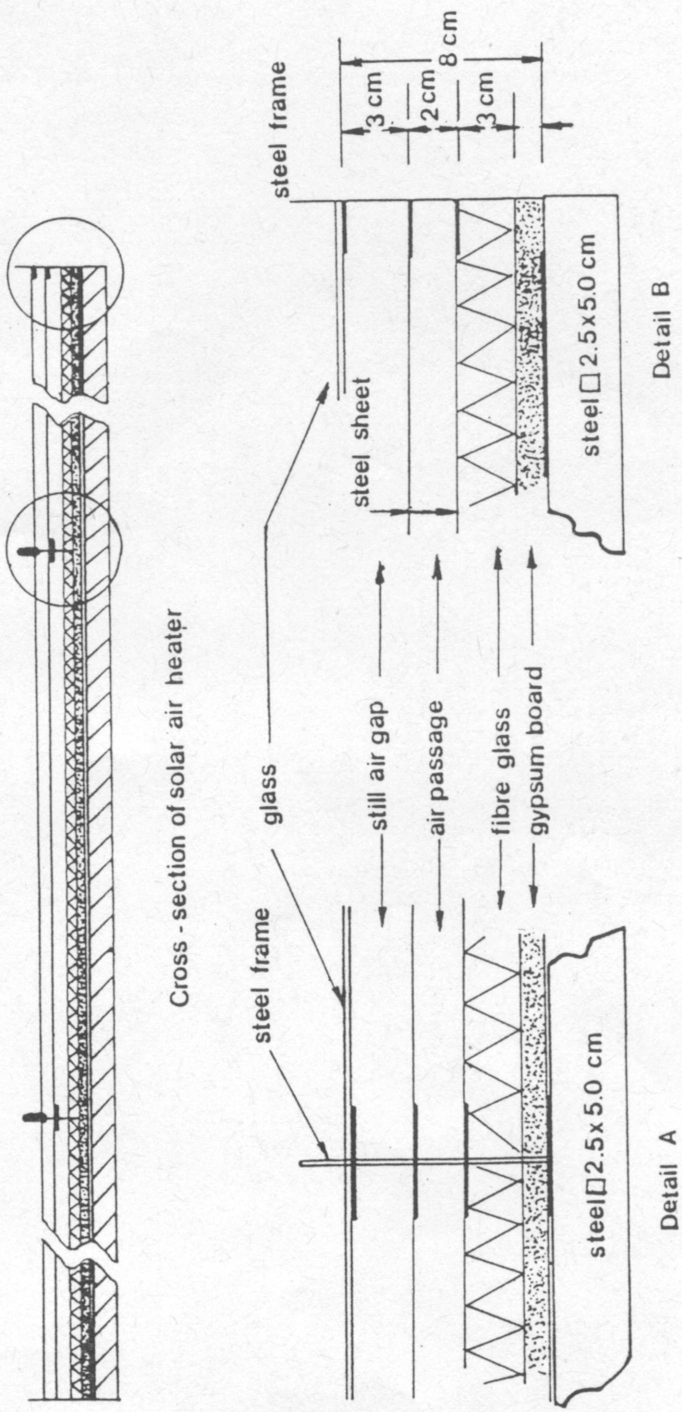
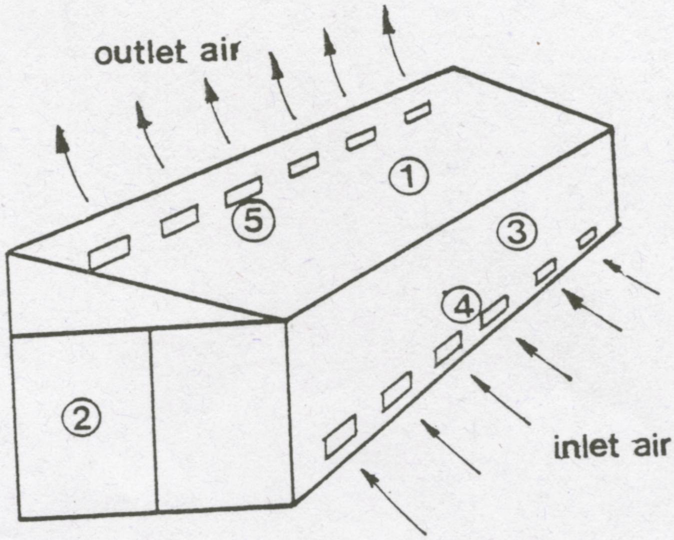
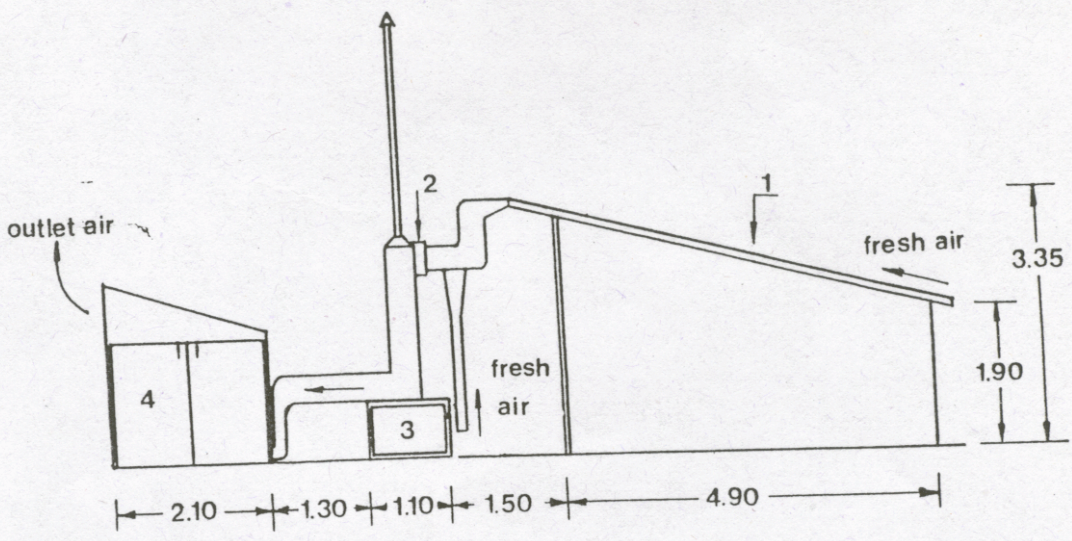


Fig. 1. Cross-section of solar air heater.



1. Glass cover, 3mm
2. Door
3. Gypsum board, 10 mm
4. Air inlet
5. Air outlet

Fig. 2. Drying cabinet.



1. Solar collector
2. Blower
3. Burner stove
4. Greenhouse

Fig. 3. Diagram showing solar drying system.

RESULTS AND DISCUSSION

System Efficiency

Daily thermal efficiency of the solar air heater was defined as the ratio of useful heat (increasing of enthalpy of air) to the solar radiation incident on the solar air heater. Experimental results showed that it was around 28% at the specific air flow rate of 0.01 kg/s-m^2 of solar air heater area. Ambient and inlet air temperatures were around 26-35°C and exiting warm air temperature was around 40-65°C while global solar radiation varied from 250-990 W/m^2.

From the experimental drying results at a constant air flow rate of 0.33 kg/s, it was observed that the first law efficiency of the solar drying system depended significantly on the moisture content of the drying product and the ratio of dry mass (dry bone matter) of the drying product to the solar receiving area. It increased with both variables as shown in Figs. 4 and 5. The former could be explained by the fact that drying rate was faster at the higher product moisture content which resulted from the higher moisture diffusion coefficient in bananas. As a result, system efficiency increased. The latter was due to higher surface area of heat and mass transfer which resulted in faster drying rate. Experimental system efficiency tended to be constant after the ratio was greater than 3.0 kg/m^2 (Fig. 4). Mean ambient temperature and relative humidity during experiments were 31°C and 56% while mean inlet air temperature and relative humidity at the inlet of the cabinet were 53°C and 25%, respectively (38 days of experiments).

From regression analysis, the relationship among the first law efficiency of the system, mean moisture content and ratio of dry mass to solar receiving area was found as follows:

$$\eta = -13.6 + 0.107\, MC + (5\ \mathrm{m^2/kg})\, DM$$

where η = the first law efficiency of the system, %
MC = mean moisture content, % dry-basis
DM = ratio of dry mass of bananas to solar receiving area, kg/m^2

Experimental daily mean moisture content varied from 81-217% while the ratio of dry mass of bananas to solar receiving area varied from 0.91-3.83 kg/m^2. The multiple correlation coefficient was found to be 0.96. The first law efficiency of the system was defined as the ratio of latent heat of moisture vaporization to energy input to the system composed of heat from solar radiation and LPG and electricity for driving the fan. During 6 days of tests, heat also included LPG which was, however, less than 3 %. An example of the calculation for the experiment on 11 March 1990 is as follows:

Mass of bananas in the morning = 255.8 kg
Mass of bananas in the evening = 217.1 kg
Mass of water evaporated = 255.8 – 217.1 = 38.7 kg
Total solar radiation incident on the solar air heater and the drying cabinet = 580.8 MJ
Heat from LPG = 0 MJ
Electricity for driving the motor = 21.2 MJ
Total energy input = 580.8 + 21.2 = 602 MJ
Latent heat of moisture vaporization = 2.4 MJ/kg
System efficiency = (38.7 x 2.4) x 100/602 = 15.4 %
Specific heat consumption = 580.8/38.7 = 15 MJ/kg
Specific electricity consumption = 21.2/38.7 = 0.55 MJ/kg

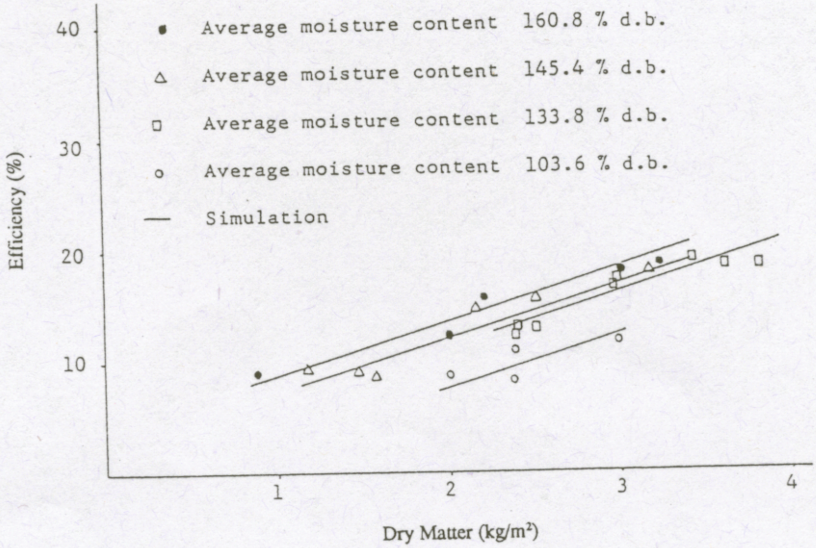


Fig. 4. Relationship between average daily efficiency of the solar drying system and moisture content of bananas at constant dry mass of bananas per unit of solar receiving area.

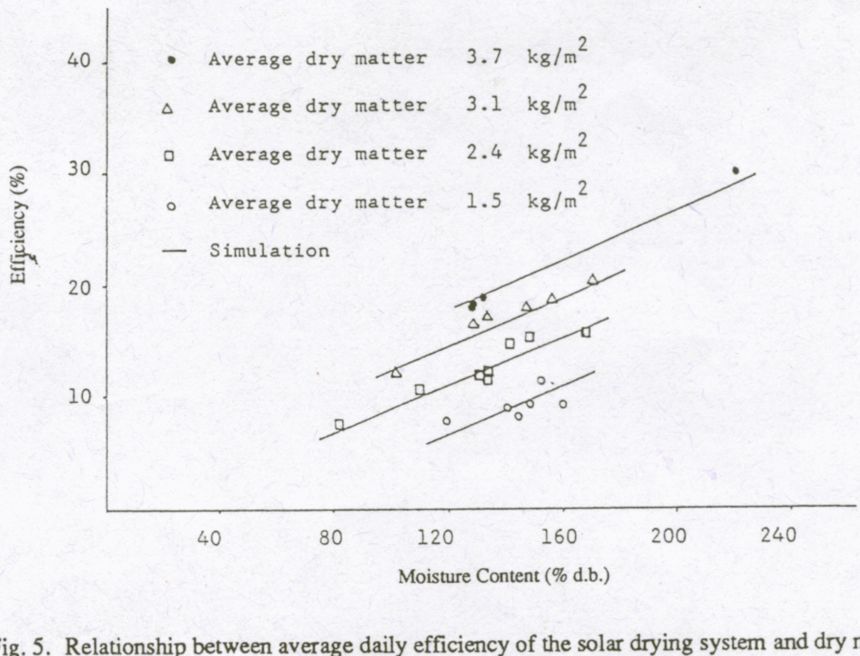


Fig. 5. Relationship between average daily efficiency of the solar drying system and dry mass of bananas per unit of solar receiving area at constant moisture content of bananas.

From the energy analysis, it was found that the average energy consumption was 15.8 MJ in terms of heat and 0.58 MJ in terms of electricity per kilogram of water evaporated.

A banana has the shape of a curved cylinder having a mean diameter of 3 cm and a mean length of 8.6 cm. Mean initial weight, dry mass and initial moisture content of fresh bananas was 63.6 g, 17.4 g and 266% dry-basis, respectively. Evolution of moisture content of a banana is shown in Fig. 6. At the beginning, it decreased rapidly and then slowly until it reached 54% dry-basis. The average drying time was seven days (6 hours/day). The average air temperature inside the cabinet was 45°C. Flattening of bananas should be done when the moisture content is approximately 70% dry-basis or after 5 days of drying.

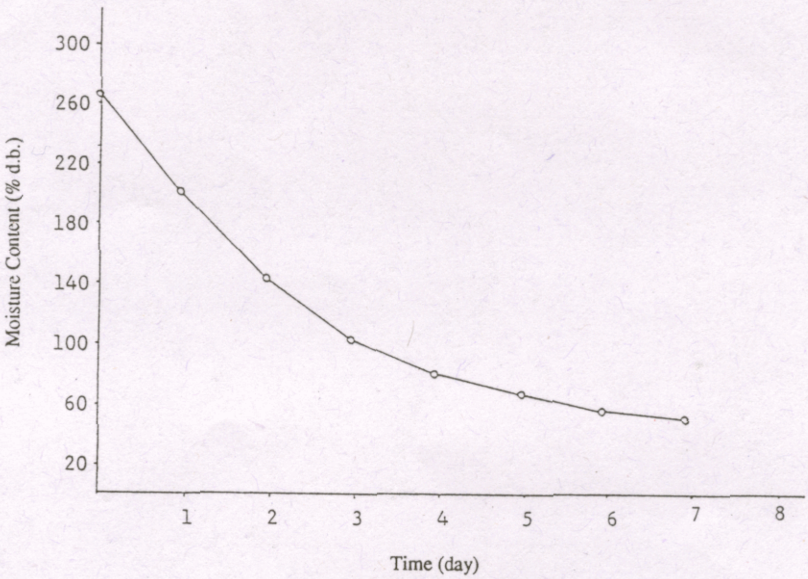


Fig. 6. Evolution of average moisture content of a banana.

Product Quality

The moisture content of a typical banana after drying was 54% dry-basis or 35% wet-basis. Its color looked yellow brown and was acceptable in the market though a little bit darker than direct sun drying due to the higher air temperature in the drying cabinet. Other physical qualities such as odour and hardness were similar. In this study sweetness was not investigated. However, it was found that the average values of total reduced sugar and sucrose of bananas dried in the solar dryer were higher than direct sun drying (Anon, 1990).

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The efficiency of the solar drying system was linearly proportional to the moisture content and the ratio of dry mass of bananas to the solar receiving area.
2. Daily thermal efficiency of the solar air heater with one transparent glass cover was 28% at the specific air flow rate of 0.01 kg/s-m^2.
3. It took seven days (6 hours/day) for one batch of drying.
4. Physical qualities of bananas dried in the solar dryer were similar to direct sun drying though the color was a bit darker.

FINANCIAL ANALYSIS

Initial cost of the drying system is US$5,200. If it is assumed that 40 kilograms of bananas per day can be produced from the solar dryer, total output will be 12,000 kilograms per year (300 days of operation). In the market in Pitsanuloke province, the price of bananas dried in a cabinet (solar dryer) is US$0.28 – US$0.08 per kilogram higher than direct sun dried bananas due to the better quality of the former. Therefore, increasing of income will be US$3,360 – US$960 per year. The operating cost of solar drying and direct sun drying is about the same because of the similar process (i.e., curing of bananas, total drying time). From a simple calculation in which interest is not accounted, the pay-back period varies from 1.5-5.4 years.

RECOMMENDATIONS

1. Due to the curing process at night which takes time and results in low production capacity, continuous or semi-continuous ventilation should be investigated in order to reduce operating time.
2. Other cheaper sources of supplemental heat should also be investigated in order to reduce operating cost.

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