DESIGN CONSIDERATIONS AND PROTOTYPE TESTS ON A PYRETHRUM FLOW SOLAR ENERGY DRYER

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ABSTRACT

This paper describes a prototype solar energy dryer specifically designed to serve the needs of the small scale rural farmer growing pyrethrum. This is a "mixed type" solar energy dryer utilising a flat plate solar collector for air preheating and direct solar radiation on the crops. Prototype test results gave a system crop drying efficiency of 25.8% for the period October 1984 to February 1985. The quality of the dried crop was as good and sometimes better than that of crops dried by other methods.

INTRODUCTION

Pyrethrum is a major source of foreign exchange currency for Kenya. It is harvested at a moisture content in excess of 75% (wb) and for safe storage and subsequent processing the moisture content must be as low as 15% (wb). The energy required for this type of moisture removal is substantial since Kenya's average year production of the wet crop is about 56,000 tons.

From the 1983/84 pyrethrum year Kenya, a non-oil producing nation, banned the use of the popular oil burning dryers by large scale pyrethrum growers due to the high cost of oil. Since the available electricity supply is already overstretched by industrial and domestic demands it cannot be diverted to crop drying purposes. There are only two alternatives: wood fired dryers or solar dryers. The former are currently well exploited, despite their fire hazards (Sebbowa 1985). But unless sufficient afforestation is undertaken these are bound to suffer the fate of the oil burning dryers. There are stringent regulations against the felling of trees and the price of wood fuel (presently as much as US$36 per ton in some areas) may in the future make wood burning dryers uneconomical. Thus the long-term solution lies with solar energy dryers.

The average annual sunshine hours over most of the pyrethrum growing area of Kenya is 7.2 hours per day (Onyango et al. 1981) and average insolation is over 0.5 kW/m^2 (Sebbowa 1984). It is these favourable conditions which led to the design of a pyrethrum solar dryer whose design and performance are reported in this paper.

Of significant importance in the design procedure were the local constraints. Firstly, whether or not the design would be acceptable to the farmers. It was established that the medium and large scale producers (with yearly yields of over 4000 kg) tend to accept novel ideas readily and still use some form of mechanical dryer (Sebbowa 1985)

Secondly, it had to be established whether the prototype made economic sense. In financial terms the small scale farmer cannot benefit from it. Already all small scale farmers supply only dried flowers to their various cooperatives. However, for the large scale farmers a mechanical dryer is ideal to avoid congestion and/or delayed harvesting. When pyrethrum is harvested late its pyrethrins content (the active ingredient) is low as are the financial returns.

It is desirable that locally available materials are sufficient for the dryer construction to save foreign currency. And because of the type of end-users, the dryer while providing jobs in the fabrication had to be simple and easy to assemble and maintain.

PYRETHRUM SOLAR DRYER DESIGN

The solar drop dryer is shown in Figure 1. It consists of a wooden dryer (2.25m x 2.3m and 2.3m height) with a 0.004m thick "ordinary window glass" roof. The cedar wood dryer walls are 0.02m thick and good thermal insulators. The dryer floor is made of similar wood boards to prevent downward heat loss. The pyrethrum flowers are dried on 10 trays stacked five high (tray spacing is 0.07m). Each tray is made of a wooden frame (1.05m x 1.9m and 0.115m deep) with galvanised wire mesh (0.006 m^2 mesh size). There is a 0.305 m^2 air inlet hole and the two outlet holes are 0.8m long by 0.101m wide. Otherwise the dryer is airtight.

To augment the direct heat supply to the crops from the dryer roof, a single cover flat plate solar collector (the air preheater) is used to pre-warm the inlet air to the dryer. The 0.68m by 3.0m collector consists of two ordinary galvanised corrugated iron roofing sheets (Gauge 30 BS) aligned with the troughs of one touching the crests of the other. This configuration, adapted from Gupta and Garg (1967) increases the air flow turbulence and hence heat transfer. The edges are sealed to make a leakproof airduct. The collector plate is housed in a galvanised iron housing from which it is insulated by glasswool (0.10m thick along the edges and 0.05m thick at the bottom). The collector cover plate is an ordinary window glass sheet (0.006m thick) secured onto the housing frame. The whole collector structure is inclined 6° to the horizontal in the north-south direction. Suitable galvanised iron ducting connects the matt black painted solar collector to a 1.5 kW electrically driven airblower and the dryer inlet (Figure 1).

EXPERIMENTS

The results to be presented cover two areas. First, the performance of the solar collector as gauged by the temperature rise of the air flowing through it. Second, the performance of the dryer (provided with warm air from the air preheater) gauged by the time it takes to dry a given batch of pyrethrum and the dryer efficiency (TDRI 1984) for the available insolation. All results were obtained under forced convection of air. Although the recommended flow rate is 0.1 kg/s, a forced convection of 0.01 kg/s per unit area of dryer bed was used since in the long-term it is desired to use a low power airblower, if not completely natural convection (Githinji 1974).

Performance of the solar air preheater

Ideally the Whillier-Hottel-Bliss efficiency equation such as quoted by McVeigh (1978) should be used to calculate the solar collector efficiency. However, for quick practical purposes a somewhat simpler relation may accurately indicate the efficiency. The relation adopted in this work is

$$\eta_c = \frac{C_p .\ m .\ \Theta}{A_c .\ G.}$$

where n_c = collector efficiency; C_p = mean specific heat of air flow through collector; θ = temperature rise of the flowing air; m = mass flow rate of air; A_c = collector surface area; and G = insolation on collector surface. The specific heat, C_p, is not linear with temperature but in the temperature range of interest (15°C to 75°C) the variation is no more than 4.4 J/kg/K or 0.4%.

The rise in temperature of the flowing air, θ, was measured with mercury in glass thermometers every 3 hours. The mass flow rate was constant at 0.0506kg/s. The insolation was measured in Langleys per day by a "Global Dome Solarimeter" at the national weather centre in Nairobi (5km from the prototype). The collector efficiency is shown in Figure 2.

Drying performance of the system

Preliminary experiments indicated that a pyrethrum flower loading of about 120 kg of wet flowers led to more effective drying when rainy spells are likely to occur. Thus with an air flow rate of 0.0506kg/s this was the loading usually adopted. Higher loading levels resulted in slow drying and often flower rotting in the middle trays. 115 kg of fresh wet flowers was evenly spread on the ten trays, leaving aside about 5kg to be naturally sun dried on an identical tray as a control sample for dried product quality.

To determine the progress of drying a 10g sample was withdrawn from a representative number of trays (Tray Nos 1, 3, 8 and 10) every 3 hours and dried under a UV electric bulb on a moisture determination balance. Drying times ranged from 4-5 days.

The dryer performance was estimated by the drying efficiency η_D. In this case the efficiency $_D$ given by TDRI (1984) was slightly modified to account for the roof direct heating;

$$\eta_D = \frac{W.L.}{G(A_c + A_D)}$$

where W = weight of moisture evaporated (kg) during sampling interval, L = latent heat of evaporation of water (kJ/kg) at mean temperature of dryer, G = insolation (kJ/m²). During sampling interval, A_c = solar collector area (m²), A_D = dryer roof area.

The mean temperature of the dryer was based on the average between inlet to and outlet from dryer temperatures. A more precise method would require a record of the actual temperatures within the drying flowers. Nonetheless the values given in Table 1 are indicative of the drying efficiencies of the prototype solar dryer.

On completion of the drying of each batch a representative sample was analysed for pyrethrins content (or quality) by ultravoilet spectrogrammetry. A sample of the "open air" sun-dried flowers was treated similarly. Table 2 compares these samples with the known pyrethrins content of flowers for the same geographical location.

DISCUSSION

The daily temperature rise indicated as expected that between the hours of 10 am and 4 pm the maximum temperature rise of the working air occurred. The overall rise was related to variation in climatic conditions particularly cloud cover. Rain apparently has less effect than cloud cover.

The Whillier-Hottel-Bliss estimates of collector efficiency shown that efficiency is highest when the insolation is lowest. But without an accurate record of temperature across the collector plate and accurate monitoring of wind to measure the various losses, the efficiencies indicated are very approximate (McVeigh 1978).

Results for the drying capability of the system confirm previous findings (Sebbowa 1984). The drying time (4 to 5 days) is similar to that reported when pyrethrum flowers are sun dried (PBK 1985). But the average drying time (50.4 hours) is somewhat longer than the 35 hours previously reported. The 44% rise is probably due to the prolonged cloud cover especially for the batch dried in the period 1.11.84/9.11.84. Further, some rewetting occurred due to rain leakage through the dryer roof for this particular batch. When this batch is excluded the average drying time is 44 hours.

Periods with the least cloud cover generally yield the shorter drying periods. Initial moisture content also affects drying time. For example, one batch with a cloud cover of 55% but a low initial moisture content 76% (wb) had a similar drying time as a second which although having less cloud cover during drying (31%) had a higher initial moisture content 82% (wb). Thus while rain during the actual drying may be less significant than cloud cover it is important at the harvesting time since this is what determines the initial moisture content.

The drying system efficiency average 25.83%, is good when prevailing weather conditions are considered. Note again the effect of cloud cover for the 1.11.84/9.11.84 batch. It must be remembered that these efficiencies are based on available insolation on the topside of the glass cover plate for the solar collector plate and the dryer roof. No account is taken of the glass reflectancy or the glass material absorption. These would reduce the available solar energy thereby raise, albeit marginally, the dryer system efficiency.

The dried flower quality is comparable with the average for the Githunguri/Limuru areas. The seemingly lower values in Table 2(b) are due to overburning when wood fired dryers are used. That is except for the Kisii area where the low value corresponds to a poor harvesting technique.

CONCLUSION

This work demonstrates that a fairly simple solar dryer designed with the aspirations of the pyrethrum growers of Kenya in mind is quite feasible. The drying times of 4 to 5 days during cloudy and sometimes rainy periods make the system relatively attractive. These times should be further improved with an blacker solar collector surface. Experiments in this direction are already underway and may be reported in the near future. However, to compensate for the somewhat longish drying times during heavy cloud cover and rainy periods a hybrid system incorporating solar energy and a wood fired system might prove best for commercial farmers. However, present wood fired dryers are very susceptible to fire. A recent survey (Sebbowa 1985) showed that most of the wood fired dryers have caught fire at one time or another. Perhaps in the end a solar energy system such as the one described in this paper is the only long term solution for pyrethrum drying.

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TABLE 1: Dry efficiencies for the prototype dryer

Batch	Available insolation (mJ)	Energy for evaporation (mJ)	Dryer efficiency (n_d%)
14.2.85/16.2.85	644.35	201.35	31.25
23.1.85/28.1.85	924.83	212.72	23.0
10.12.84/15.12.84	788.88	225.91	28.6
27.11.84/2.12.84	901.53	240.91	26.7
1.11.84/9.11.84	1118.38	219.30	19.6

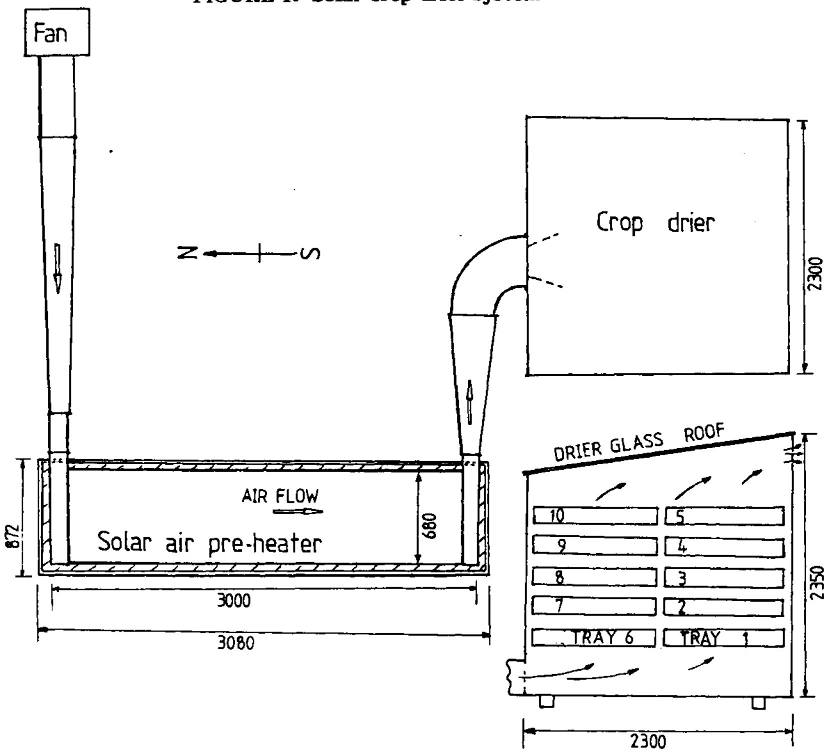
TABLE 2(a): Quality (pyrethrins content of flowers dried in prototype)

Batch	Pyrethrins content %	
	Dryer	Control sample (Sun dried)
14.2.85/16.2.85	-	-
23.1.85/28.1.85	-	-
10.12.84/15.12.84	1.670	1.680
27.11.84/2.12.84	1.620	1.680
1.11.84/9.11.84	1.626	1.640

TABLE 2(b): Average national quality (pyrethrins content) of flowers (some flowers firewood dryer dried, others sun dried)

Locational area		Pyrethrins content %	
Githungri	(1°S 37°E)	1.65	(Supplied first three samples)
Limuru	(1°S 37°E)	1.50	(Supplied last two samples)
Nakuru	(0°N 36°E)	1.49	
Meru	(0°N 37°E)	1.90	
Kisii	(0°N 35°E)	1.20	(99% sun drying)
Molo	(0°N 36°E)	1.50	

FIGURE 1: Solar crop drier system



Solar air heater

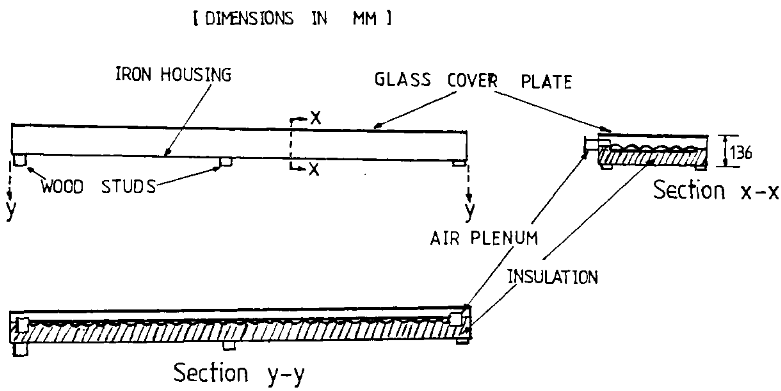


FIGURE 2: Insolation and collector efficiency vs day