The Development of a Photovoltaic Powered Forced Convection Solar Maize Dryer for Use in Sub-Saharan Africa

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ABSTRACT

This solar crop dryer dries 90 kg amounts of maize, as on small farms in east and central Africa, from about 33.3% moisture content dry basis to 14.3% dry basis (d.b.) for storage in one day of clear weather conditions and is equal to less time than open air sun drying. The dryer has been developed through several stages of postgraduate research, laboratory and field development and analytical modelling. Passive temperature control is a major aspect of the design, so the grain is not heated above 60 °C. The solar, thermal and electrical characteristics of the dryer were measured under a solar simulator in Scotland and under field conditions in Malawi. A collector thermal efficiency of 80% and a drying efficiency of 58% were obtained for the dryer. The principles in improving efficiency in the present design include a solar air collector that can be occasionally oriented to increase solar gain; a small photovoltaic (PV) powered DC fan sized to give optimum drying rate and passive temperature control to 60 °C grain temperature. A financial analysis showed that the dryer technology is viable with a payback period under 3 years.

1. INTRODUCTION

In tropical Africa, sun drying is the traditional technique used for drying maize. Maize grain is usually spread in the sun on a suitable surface, and cobs are hung from eaves of buildings or trees or left on the stalks in stooks or bundles for a period of 4-6 weeks. Very small producers owning less than 7,000 m² tend to dry and/or store undehusked maize by exposing the cobs to the atmosphere on the ground, or by suspending them from eaves or trees. Larger producers owning over 7,000 m² use ventilated woven teak pole and grass thatch roof granaries in combination with a 4-6 weeks period of preharvest drying in the field to reach suitable moisture content which inhibits mold infection, usually 25%-28% (d.b.), before storing the cobs in the granaries. The husks are left on the cobs because they provide a degree of protection from insect damage. The preharvest drying period usually invites unacceptable product losses through pests, molds, wind and rain, and infections started in the field are perpetuated or multiplied during storage. This practice also leaves insufficient time to prepare the land for the next planting season. In the heavy rainfall areas of tropical Africa, losses can be as high as 10%-50% [1].

In the case of grain spread on the ground, shallow bed depths (about 2 grains thick) require relatively large areas of land on which to spread the grain. There is also need for labor to be on hand to move the crop under cover in the event of sudden rains and also to scare away predators. The direct exposure to sunlight (ultra-violet radiation) greatly reduces some nutritional contents such as vitamins [2]. Maize grain dried in this way is normally milled immediately after drying or is stored in gunny sacks when the moisture is reduced down to 14%-15% (d.b.). Grain for immediate milling need not go down to this level, moisture content in the range of 20%-25% (d.b.) is normally adequate.

The solar dryer study reported here involved developing a maize grain dryer for remote village and smallholder farmer use in tropical Africa. Field tests of the drier were conducted in Malawi, central Africa.

2. RESEARCH OBJECTIVES

The main objective of this research was to develop a small-scale forced convection solar grain dryer without external power supplies such as grid electricity and fossil fuel. The main design constraint was that the drying air temperature should not exceed 60 °C to prevent grain overheating and cracking. The 60 °C upper limit on the drying air temperature is suitable for drying grain for human consumption [3]. The specific objectives include the following:

1. Developing a solar dryer with an efficient drying capability, coupled with minimal labor requirements, in a controlled environment.
2. Studying the possibility of passive drying-temperature control in order to prevent grain overheating and cracking by the use of a PV-driven d.c. fan.
3. Investigating conditions and extended time periods favoring the growth of microbes, especially fungi which produces poisonous aflatoxin.
4. Studying the use of locally resourced materials and components, at reasonably low cost, to ensure the cost-effectiveness of the dryer technology to local farmers.

3. PROCEDURE

3.1 Design of Solar Dryer

The basic early designs of the dryer were developed by Grainger [4] and Othieno [5] as shown in Figs. 1 and 2. In these designs, air is heated in a collector and passes into the base of a plenum chamber before moving upwards through the grain bed and is exhausted through a chimney. The collector absorber in Fig. 1 is a matt black flat metal plate, and that in Fig. 2 is a matrix of matt black perforated aluminium plates.

Fig. 3 shows the solar dryer design reported in this paper. This dryer evolved from the designs shown in Fig. 1 and Fig. 2. The solar dryer in Fig. 3 differs from those in Figs. 1 and Fig. 2 in that

1. its collector absorber mesh is made of woven sisal rope grids which can be resourced locally and cheaply,
2. its collector tracks solar radiation by manual rotation of the collector module to increase heat gain,
3. its collector has a capability of incorporating honeycomb transparent insulation to increase its thermal mass,
4. its collector module carries a PV solar panel to drive a d.c. fan for controlled air circulation and drying air temperature, and

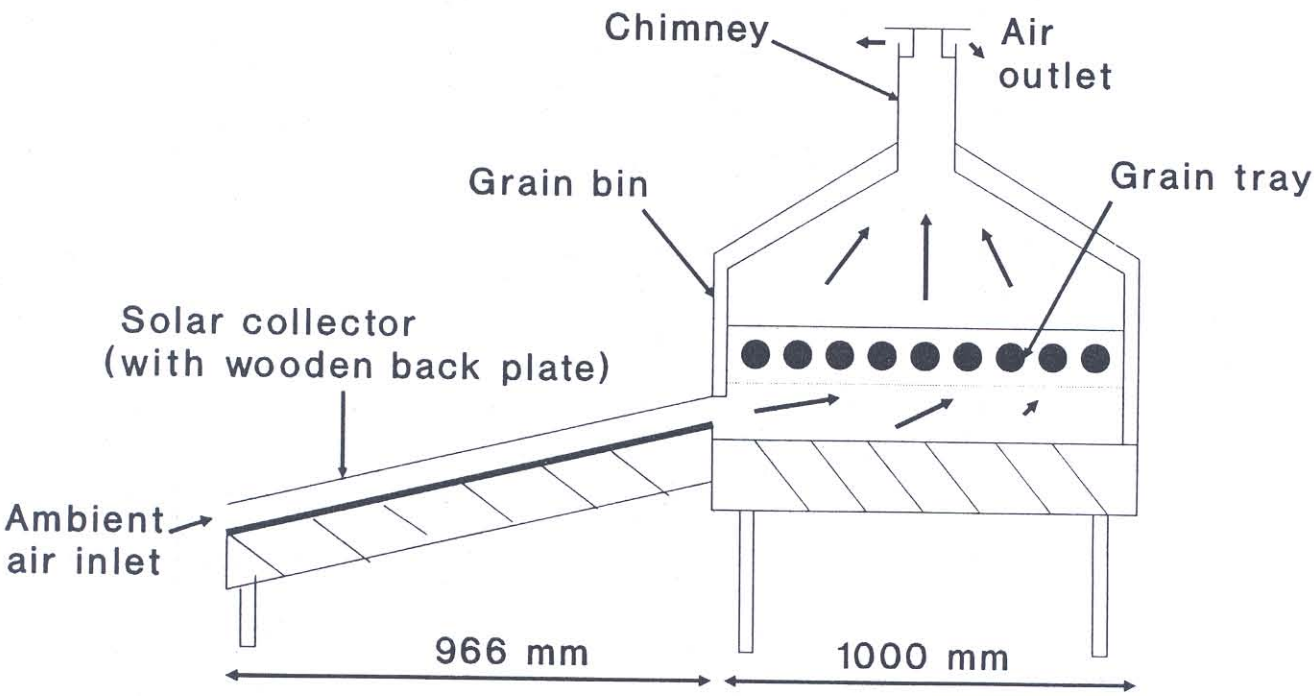

Fig. 1. Schematic diagram of the small scale natural circulation solar maize dryer built in Kenya. The dryer incorporates a flat (wooden) plate solar air heater (Grainger [4]).

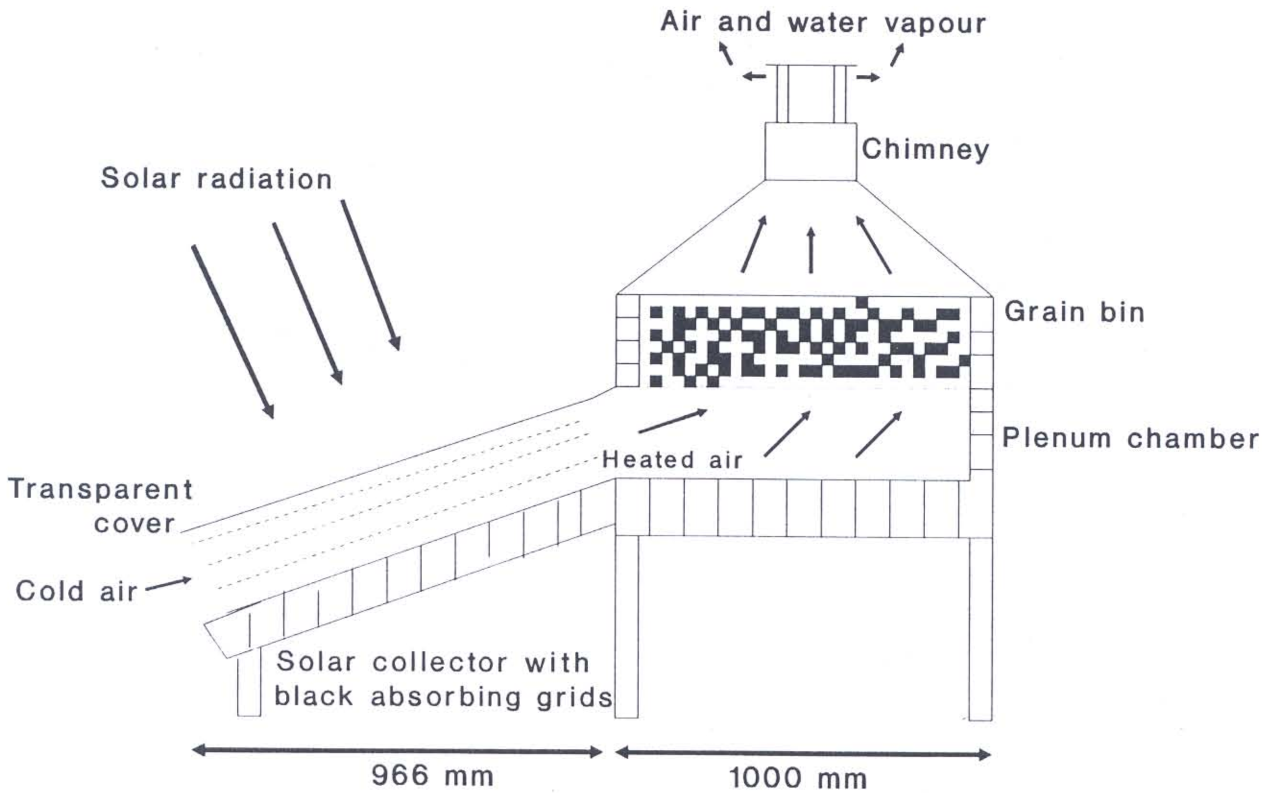

Fig. 2. Schematic diagram of the small scale natural circulation solar maize dryer incorporating a multilayer aluminium grid solar air heater. The dryer was built and tested in Kenya (Othieno [5]).

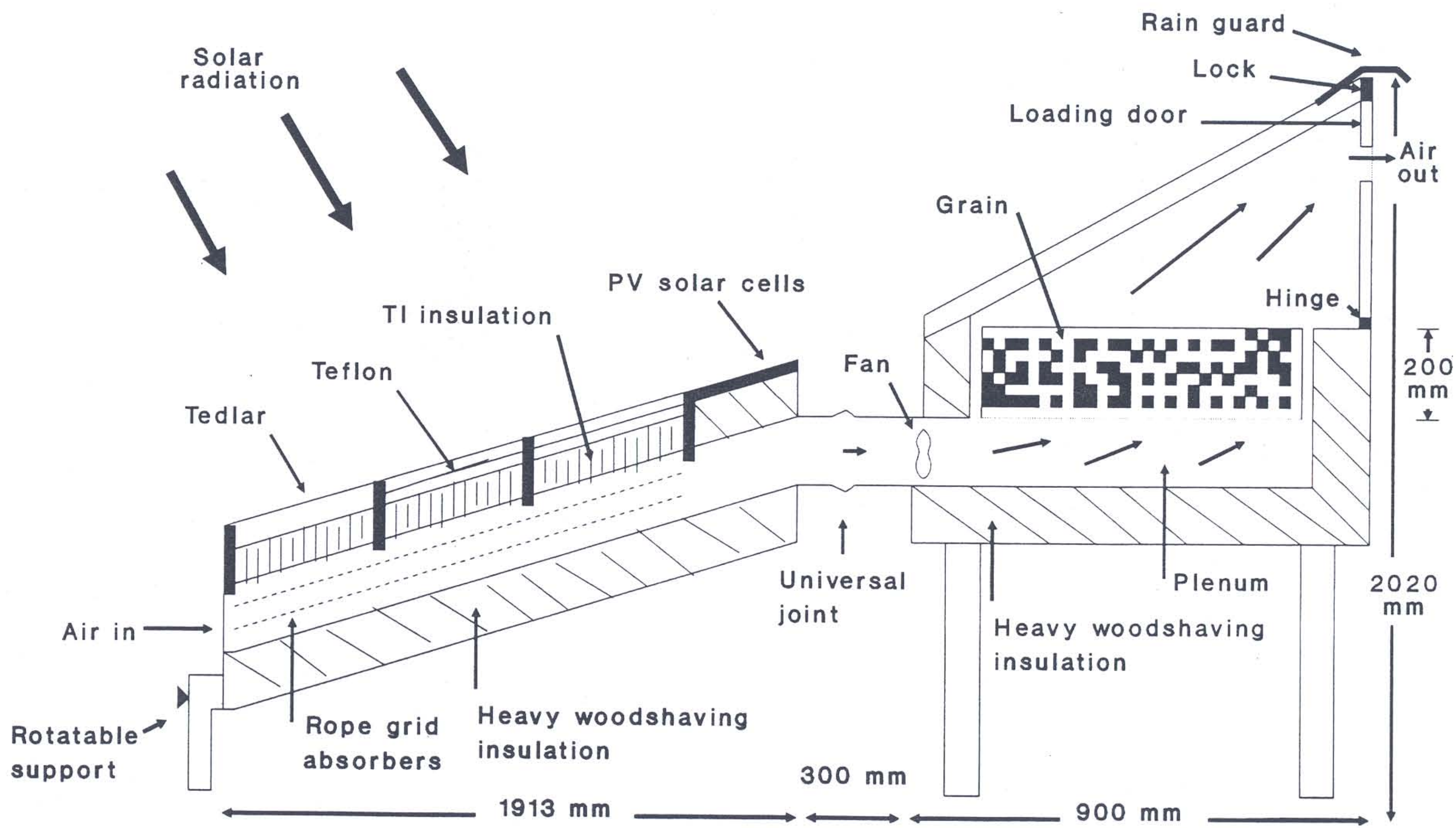

Fig. 3. Schematic diagram of the solar grain dryer incorporating PV-powered forced air circulation built and tested in Malawi.

5. its drying chamber has no chimney.

The actual sizing of the dryer was based on the following information:

1. The quantity of maize grain to be dried.
2. Maize grain properties such as initial moisture content and desired final moisture content.
3. The optimum safe drying air temperature.
4. The existing solar radiation intensity, ambient air temperature, wind velocity and relative humidity at the dryer location.

The amount of heat required and the quantity of air needed for drying was estimated using a psychrometric chart. The amount of water to be extracted from the grain is calculated from the expression

$$m_w = \frac{(M_i - M_f)}{(100 - M_f)} m_i \tag{1}$$

where m_i = initial grain mass, M_i = initial moisture content of grain on a wet basis, M_f = final moisture content of grain on a wet basis. The amount of heat required to evaporate a mass of water m_w from the grain is therefore given by

$$q_{ev} = h_{fg} m_w \tag{2}$$

where h_{fg} = latent heat of evaporation (= 2.8 MJ/kg for maize grain). The amount of energy captured in the collector is estimated from

$$q_c = (\tau\alpha)_e \overline{I_h} \, \overline{\eta} \, A_e \tag{3}$$

where $(\tau\alpha)_e$ = the effective transmittance-absorptance product, $\overline{I_h}$ = average global solar radiation falling on the horizontal collector per day, $\overline{\eta}$ = average device efficiency (= product of average collector thermal efficiency and average dryer moisture removal efficiency), A_e = effective collector area. By equating Eq.(2) to Eq.(3), the collector dimensions can therefore be estimated.

In addition to the determination of collector dimensions, the optimum collector depth and number of absorber rope meshes must be also be determined [4]. The number of absorber layers depends on the void factor, F_v, defined as the fraction of radiation passing through the holes at normal incidence. The optimum number of absorber layers, n, can be estimated to the nearest whole number using the relationship

$$F_v^n = 1 - F_v \tag{4}$$

The optimum gap between adjacent absorber layers, δ, is related to the effective hole diameter, D, by

$$\delta = 3D \tag{5}$$

The overall optimized collector depth, d, can be calculated from

$$d = \delta (n+1) \tag{6}$$

The collector inside dimensions were 1.0 m x 1.5 m, and the drying chamber inside floor dimensions were 1.0 m x 1.0 m. A 1.0 m x 0.3 m PV solar panel (nominal power = 10 W and voltage = 12 V) was placed at the collector head as shown in Fig. 3. A 5 W, 12 V d.c. fan was placed at the drying chamber air inlet (Fig. 3). All dryer walls had 0.08 m wood shaving insulation. Collector surfaces are wood, painted matt black. The drying bin was raised up 1.0 m from the ground. All opaque walls were insulated with some form of local material such as wood shavings or diatomite material. The wooden structure was treated with anti-termite and other preservatives, e.g. creosote; care was taken to prevent contamination of the grain.

3.2 Performance Assessment Models

The temperature gain produced by the air heater can be expressed as follows:

$$(T_{fo} - T_{fi}) = \frac{A_c \eta_c G_T}{C_p \dot{m}_a} \tag{7}$$

where T_{fo} is the collector output air temperature, T_{fi} is the collector inlet air temperature, A_c is the collector aperture, η_c is the collector thermal efficiency, C_p is the collector air specific heat capacity, G_T is the instantaneous incident solar irradiance and $\dot{m}_a$ is the collector air mass flow rate. Eq. (1) is very useful in describing the performance of the air heater in the photovoltaic powered variable speed forced convection solar dryer. Eq. (1) shows that when the incident solar radiation level increases/decreases, the mass flow rate increase/decrease proportionally. Drastic changes in the temperature gain when insolation and mass flow rate varies can be minimized provided all the dryer characteristics are properly matched. The instantaneous grain moisture content at any given time, t, can be computed using the following expression:

$$M(t) = \left[\frac{m_g(0)}{m_g(t)} \left[M(0) + 1 \right] \right] - 1 \tag{8}$$

where $m_g(0)$ is the initial grain mass, $m_g(t)$ is the instantaneous grain mass, $M(0)$ is the initial moisture content dry basis. The dryer thermal efficiency can be expressed as follows:

$$\eta_d = \frac{m_w h_{fg}}{m_a C_p (T_d - T_{fi})} \tag{9}$$

where m_w is the mass of grain moisture evaporated, h_{fg} is the latent heat of evaporation of water, $\dot{m}_a$ is the air mass flow rate, C_p is the specific heat capacity of the air, T_d is the drying air temperature and T_{fi} is the dryer collector inlet air temperature. The dryer pick-up efficiency is expressed as follows:

$$\eta_p = \frac{m_w}{m_a \Delta t (W_{g,e} - W_{g,i})} \tag{10}$$

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where m_w is the mass of grain moisture evaporated, h_{fg} is the latent heat of evaporation of water, $\dot{m}_a$ is the air mass flow rate, C_p is the specific heat capacity of the air, T_d is the drying air temperature and T_{fi} is the dryer collector inlet air temperature. The dryer pick-up efficiency is expressed as follows:

$$\eta_p = \frac{m_w}{m_a \Delta t (W_{g,e} - W_{g,i})} \tag{10}$$

where m_w is the mass of moisture evaporated in time Δt, $\dot{m}_a$ is the air mass flow rate, $W_{g,e}$ is the grain exit air absolute humidity ($\approx$ adiabatic saturation humidity) and $W_{g,i}$ is the grain inlet (plenum) air absolute humidity. In the process of drying when grain stays overnight in the dryer, a moisture re-absorption factor, R_M, can be used as an indicator in cases of grain rewetting due to high night time relative humidities as follows:

$$R_M = \frac{(M_{sr} - M_{ss})}{M_{ss}} \tag{11}$$

where M_{sr} is the moisture content (dry basis) at sunrise, M_{ss} is the moisture content (dry basis) at sunset of the preceding day. Moisture re-absorption occurs when $R_M > 0$ and further moisture loss occurs when $R_M \leq 0$.

The instantaneous d.c. fan solar energy utilization efficiency is expressed as follows:

$$\eta_f = \frac{I_f V_f}{A_{pv} \bar{\eta}_{pv} G_T} \tag{12}$$

where I_f is the fan current, V_f is the fan voltage, A_{pv} is the photovoltaic solar cell area, $\bar{\eta}_{pv}$ is the solar cell solar energy conversion efficiency and G_T is the incident solar irradiance.

3.3 Test Procedures

A complete dryer prototype was designed and built in the laboratory. In the laboratory, dryer characterization experiments were conducted under a solar simulator. Dryer pressure drop and air flow characteristics were determined under wet maize grain load conditions. Dryer pressure change was measured by inserting two 10 mm diameter flexible tubes in the drying chamber sides which were connected to a digital Greer electromanometer with an accuracy of ±0.5 Pa. Air speed was measured in the duct connecting the collector and the drying chamber with a type E.T.A. 3000 hot wire flow meter with a measuring uncertainty of ±10%. Fan pressure change data was obtained from the manufacturer. The current and voltage characteristics of the photovoltaic module and the DC fan were measured with type DA116 digital avometers with an accuracy of ±0.05 mA and ±0.01 V respectively. Air temperature was measured at the collector air outlet (4 points), drying chamber plenum (4 points), grain bed top, and in the ambient air, with copper/constantan 34 s.w.g. thermocouples connected to a type 1694F 20-channel Comark selector unit and a type 5000 10-channel Comark digital display unit. A CM5 Kipp and Zonen solarimeter was used to measure solar simulator irradiance with an accuracy of ±0.3%. The dryer was built in the field with the same laboratory specifications. The use of locally available materials was, however, strongly emphasized. The parameters measured in the laboratory were also measured in the field in addition to grain moisture content.

Maize grain, 90 kg freshly harvested with an initial moisture content of 33.3% dry basis, was used in the drying runs. Grain was loaded at 8:00 a.m. and unloaded at 1:00 p.m. the following day. Seven 50 g samples were placed in small cylindrical wire mesh baskets in the grain bed at different depths and locations. The samples were weighed every 30 minutes. The initial grain moisture content was determined by the air oven method.

4. RESULTS AND DISCUSSION

4.1 Component Matching Characteristics

Fig. 4 shows the dryer and fan pressure variation with respect to air volume flow rate in the dryer. It can be seen in Fig. 4 that in the dryer operating range of 0-160 m³/h, the total dryer pressure change remains under 30 Pa which falls within the safe operating range of the fan. A least squares analysis gave the following relationship between dryer pressure change and volume flow rate:

$$\Delta p_D(Pa) = 0.1832\ \dot{V}_a \tag{13}$$

with an R-correlation coefficient of 0.99, where $\Delta\rho_D$ is the pressure change in Pa and $\dot{V}_a$ is the volume flow rate in m³/h. Fig. 5 shows the current-voltage characteristics for the PV module and the permanent magnet d.c. fan. The fan characteristics perfectly follows the maximum power points of the PV module, indicating a good component match. This shows the typical benefit of directly coupling permanent magnet d.c. fans with photovoltaics. The PV module used in this study was of the amorphous silicon type with a solar energy conversion efficiency of 8%. A mean solar energy utilization efficiency of 33% was calculated for the d.c. fan load. A mean air heater thermal efficiency was found to be about 80%.

4.2 Temperature Control

Drying air temperature control is achieved through the strategy of using a PV-powered air mover. Early ideas on the application of photovoltaics in solar crop driers are outlined by Brenndorfer et al. [2]. The air temperature from the collector rises quickly in the morning as the irradiation increases. Near to 60 °C, the PV-powered fan increases the air speed through the collector and into the grain, so the temperature does not increase further. Fig. 6 is a typical plot showing the passive temperature control for data of day 1/run 1. In Fig. 6 it can be seen that large fluctuations in the incident solar irradiance in the morning (8:00 a.m. - 11:00 a.m.) did not affect the steady dryer air temperature increase. A maximum uniform dryer air temperature of 60±3 °C was attained at 11:00 a.m., and it was maintained up to about 2:00 p.m. despite a steady drop in solar irradiance at about 12:30 p.m. The dryer duct air speed variation corresponds to the variation of the incident solar irradiance except in cases of large short interval fluctuations of the latter in the morning when air speed does not respond to these large short interval fluctuations. The ambient air temperature was fairly uniform with an average of about 25 °C.

4.3 Grain Drying

Maize grain, 90 kg of freshly harvested with an initial moisture content of 33.3% (d.b.), was used to study drying characteristics of the solar dryer. A total of 5 runs were conducted in the field in Malawi. Results from drying run 1 are presented here. A weather synopsis on day 1 of this run included intermittent cloud patches throughout the day with some afternoon showers. Dryer thermal and moisture pick-up efficiencies of 58% and 77% respectively were found to be significant improvements over efficiencies of the order of 30% obtained by Grainger [4] and Othieno [5] in their natural circulation models of the dryer built in Kenya. Fig. 7 shows the drying curves of the dryer grain and the sun dried control sample of the same mass for two consecutive days. Drying times taken to reach

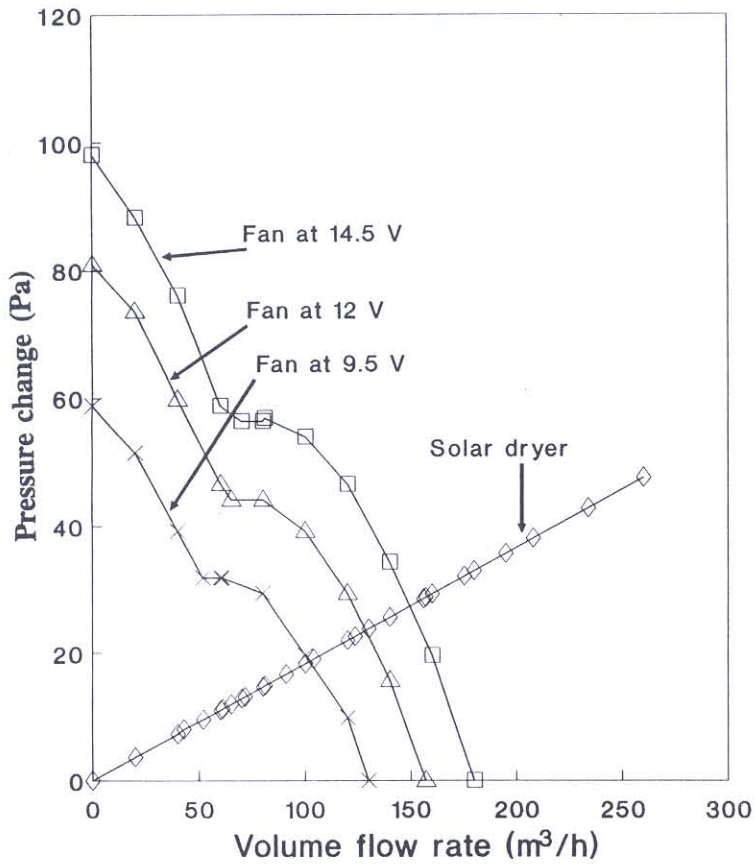

Fig. 4. Variation of solar dryer and d.c. fan pressure change with respect to drying chamber inlet duct air volume flow rate.

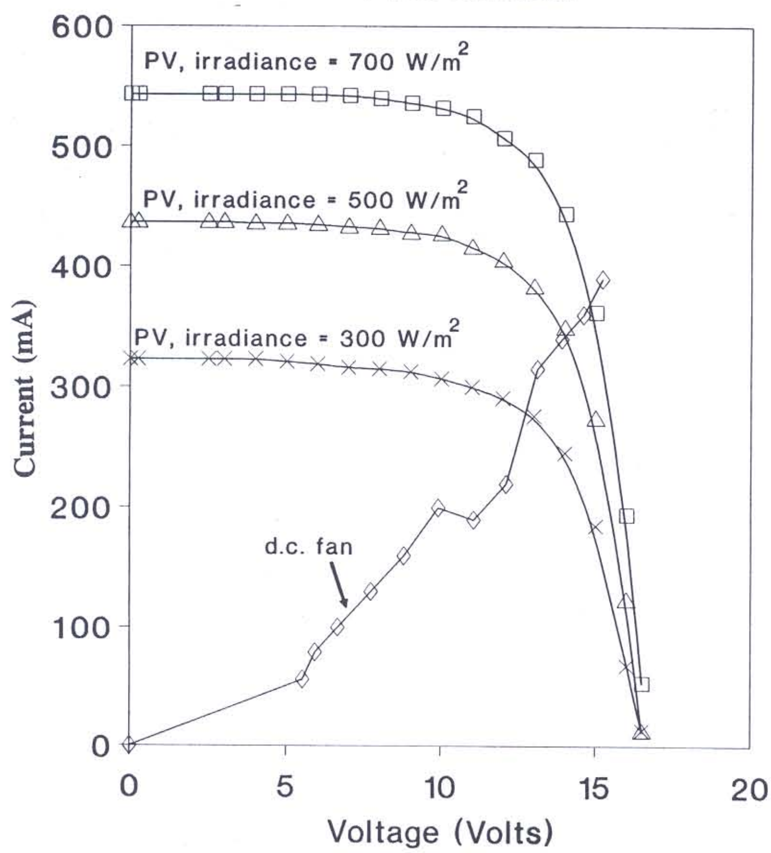

Fig. 5. PV module and d.c. fan current-voltage characteristics.

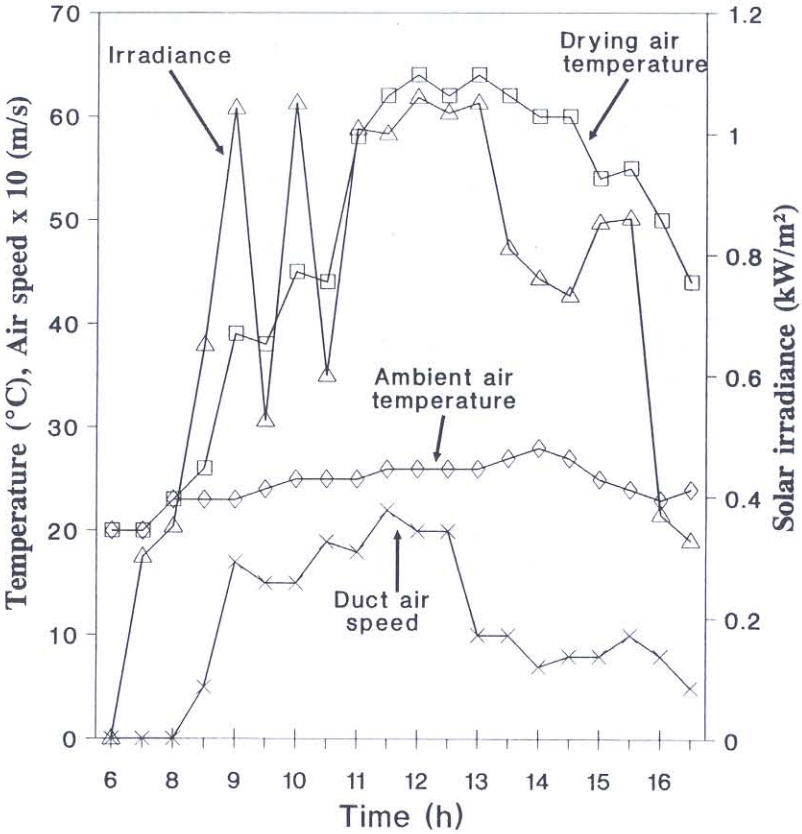

Fig. 6. Performance of the solar grain dryer on day 1 of the first drying run.

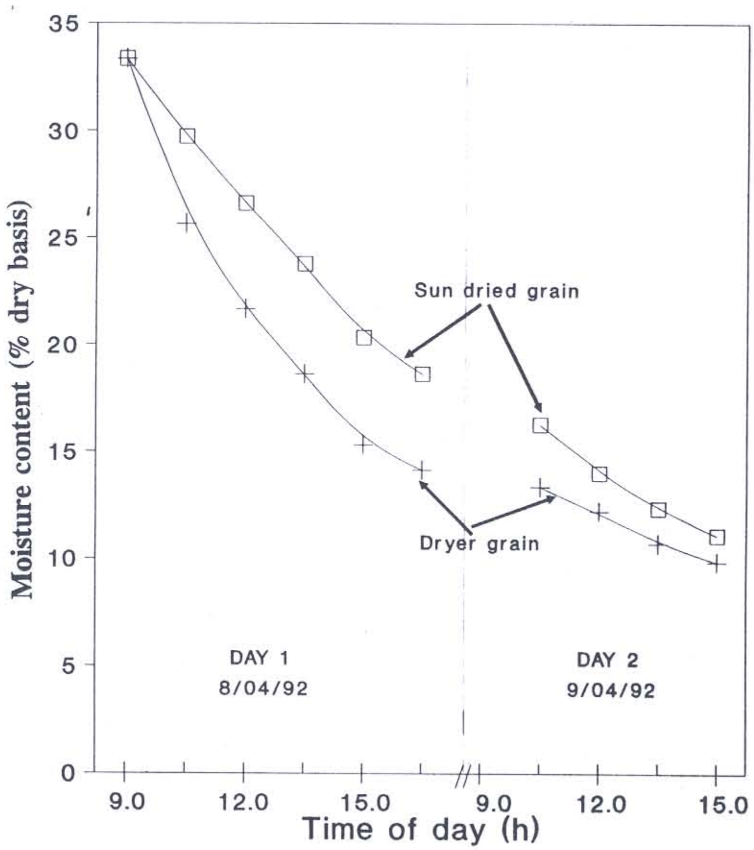

Fig. 7. Grain moisture content variation with time on day 1 and 2 of the first drying run.

the safe milling moisture content of 25% (d.b.) were 1.4 hours and 2.9 hours for the dryer grain and the control respectively. Drying times taken to reach the safe storage moisture content of 14.3% (d.b.) were 7.0 hours and 27 hours (night hours inclusive) respectively. The long drying time achieved with the control sample was due to a sudden increase in the ambient air relative humidity induced by the afternoon rain showers on day 1. On this day the sun dried grain had to be gathered quickly and put undercover. This was a typical experience of the inherent day-to-day problems faced by people when drying grain in the open. Gathering large quantities of grain spread on the ground in times of sudden rains is labor intensive and results into substantial grain rewetting and loss. A moisture re-absorption factor of -0.044 indicated that the drying process continued throughout the night. Night time drying was attributed to the thermal inertia of the rope grid absorber solar air heater developed in this study.

When the grain had reached a mean moisture content of 14.3% (d.b.), its color and texture were examined in comparison with the sun dried grain quality. The dryer grain appeared superior although no quantitative data was available in support of this. Flour samples were also examined and the dryer grain flour looked and tested better than the sun dried grain flour in a local porridge dish.

5. FINANCIAL ANALYSIS

5.1 Cost of Solar Dryer

Table 1 gives a list of the construction materials and the cost including labor. Apart from the transparent solar collector covers, all materials were obtained locally, and the construction work was conducted by a qualified carpenter. The most expensive items in the dryer construction were the Tedlar/Teflon transparent collector covers which were purchased in the United Kingdom at £230. Artisanal designs can include cheaper plastic covers such as polythene sheets which are locally manufactured and are sold at £0.60/meter retail. Typical PV panels available in Malawi are large size panels with nominal power output above 30 W and costing more than £500 per panel. These panels are mainly tailored for large load requirements such as rural lighting, water pumping, communications and hospital refrigeration. Hence in a typical artisanal solar dryer, the most expensive component is the PV solar panel. The PV panel used in the present dryer was a small 10 W panel of dimensions 1.0 m x 0.3 m, purchased at £90 in the United Kingdom. Smaller panels are obtainable from abroad through commercial agents. All the other materials listed in Table 1 were locally resourced.

The estimated labor charge given in Table 1 would be incurred in cases where self-employed artisans are used to build dryers, otherwise there would be no such charges in do-it-yourself situations. The minimum wage for a laborer is about £120/year. For a drying season of 4 months (2 in the first quarter and 2 in the last quarter of the year) the total labor cost is £40/year. Labor includes grain loading, unloading, transportation, spreading on mats or bare ground, regular stirring and keeping constant watch against birds, insects, vandals and sudden rainfall.

From Table 1 it can be seen that a solar dryer built by village artisans costs about half the cost of the field work prototype.

5.2 Cash Flow Analysis

Table 2 gives the projected cash flow statement for the solar grain dryer over the dryer life of 10 years. The dryer capital costs amount to £398 for a dryer built by village artisans. Under operating costs, farm inputs include seed grain and fertilizer; labor include crop husbandry and dryer operation; maintenance include repainting of dryer and replacing of collector plastic covers; transport include

Table 1. List of solar dryer construction materials and cost.

Item	Quantity	Cost for experimental dryer (£)	Estimated cost for dryer built by village artisans (£)
25 mm x 76 mm pine	100 mm	17	17
6 mm x 2400 mm x 1200 mm plywood	6 off	13	40
1.0 m x 0.5 m mounted single and double Tedlar/ Teflon collector covers	4	230	100
0.33 m x 1.0 m amorphous silicon PV solar module	1	90	100
5 W, 12 V DC fan	1	50	15
Matt black paint	12 liters	41	41
Black creosote	5 liters	14	14
Wood glue	0.8 liters	2	2
Wood preservative	5 liters	14	14
Transaparent Insulation (TI) material	1.5 m^2	30	-
2 mm thick jute ropes	13 kg	15	5
White paint	5 liters	12	-
1.0 m x 5.0 m wire gauze	1	2	2
Screws and nails	3 packets	6	6
Hinges	6 pairs	4	4
Fasteners	8	15	12
Labor	-	26	26
Total (£)		601	398

Table 2. Projected cash flow statement over a dryer life of 10 years.

Year	0	1	2	3 10
CAPITAL COSTS (£) Dryer	398	0	0	0 0
OPERATING COSTS (£)				
Farm inputs	0	50	50	50 50
Labor	0	60	60	60 60
Extra inputs	0	35	35	35 35
Extra labor	0	20	20	20 20
Maintenance	0	25	25	25 25
Transport	0	10	10	10 10
TOTAL COSTS (£)	398	200	200	200 200
REVENUE (£)				
Sales + food	0	161	161	161 161
Extra sales	0	183	183	183 183
TOTAL REVENUE (£)	0	344	344	344 344
NET CASH FLOW (£)	-398	144	144	144 144

hiring an ox-driven cart. Extra inputs and labor include the additional amounts required due to the dryer technology. Apart from reducing grain loss at the drying level, the dryer requires extra grain to dry which the farmer has to grow using extra seeds which he has to buy. Revenue is realized from grain sales at the farm gate price of £0.17/kg. Maize grain used for the farmers consumption is valued equally. Extra sales are realized from increased productivity due to the dryer technology.

The net present value (NPV) at an average discount rate of 10% (= prevailing mean interest rate for borrowing) is calculated over the dryer life and is equal to £486.88. The internal rate of return (IRR) is found to be 36%. Since NPV > 0 and IRR > 10% (the interest rate for borrowing), the dryer is a viable technology. The dryer payback period is found to be 2.8 years.

5.3 Sensitivity Analysis

The sensitivity of the NPV and the payback periods with respect to changes in the key assumptions was conducted. Fig. 8 shows a linear plot of dryer NPV versus maize price index. A maize price index = 3 corresponds to the current dryer NPV of £486.88. A 10% reduction in the maize price (index = 2) gives an NPV of £275.49, while a 20% reduction (index = 1) gives NPV = £64.10. A 10% increase in the maize price (index = 4) gives NPV = £698.27, and a 20% increase (index = 5) gives NPV = £909.66.

Fig. 8 also shows an exponential decay between dryer payback period and maize price index. A maize price index = 3 corresponds to the current payback period of 2.8 years. A 20% reduction in the maize price gives a payback period of 5.3 years, and a 10% reduction gives a payback period of 3.6

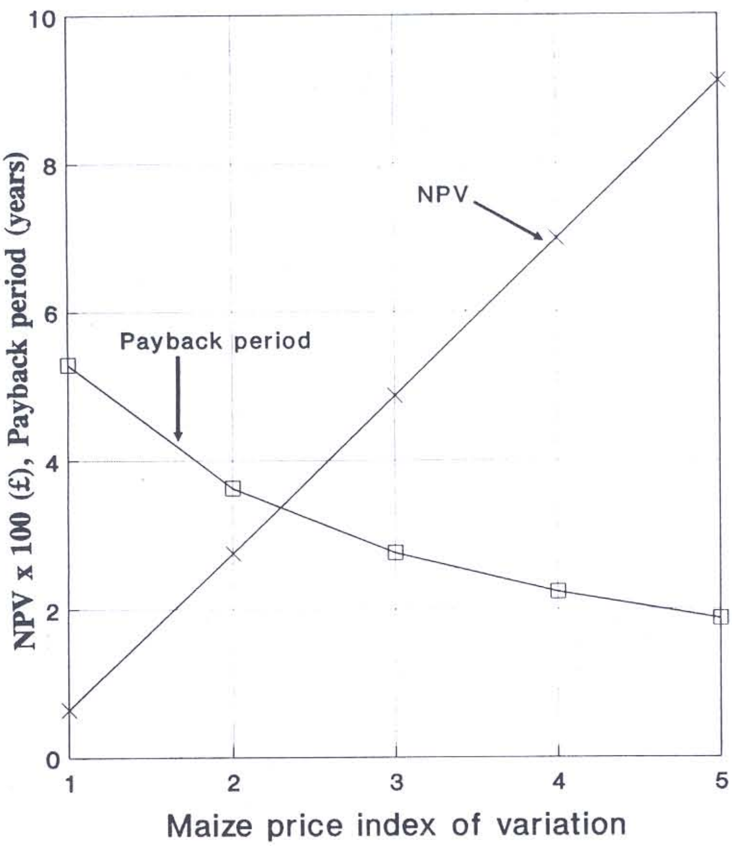

Fig. 8. Solar dryer NPV and payback period variation with maize price. Key to price indices: 1 = 20% reduction; 2 = 10% reduction; 3 = current price; 4 = 10% increase; 5 = 20% increase.

years. A 10% increase in the maize price gives a payback period of 2.2 years, and a 20% increase gives a 1.9 years payback period.

Fig. 9 shows a logarithmic decay between dryer NPV and capital costs index. A capital cost index = 4 corresponds to the current capital cost of £398 and NPV of £486.88. At much higher capital costs (> £800), negative NPV's are achieved in an almost linear variation. Capital costs greater than £800 therefore make the dryer option not viable.

5.4 Recommended User Groups

The dryer can be suitably recommended for use in a particular area if the marketing channels of the product are well known. In Malawi, grain drying is mainly done by smallholder producers in rural areas, some of whom belong to co-operatives and farmers clubs. In contrast to Malawi, co-operatives in Kenya are widespread among farmers and Othieno [6] had previously recommended the dryer to these groups due to the high capital cost of the dryer. The dryer tested in Malawi was estimated at £398 capital if built mostly from local materials. As this figure is still unaffordable by individual smallholder farmers the best locations for the solar dryers have been identified on a shared basis as (a) single or multiple villages (b) farmers clubs and (c) co-operatives.

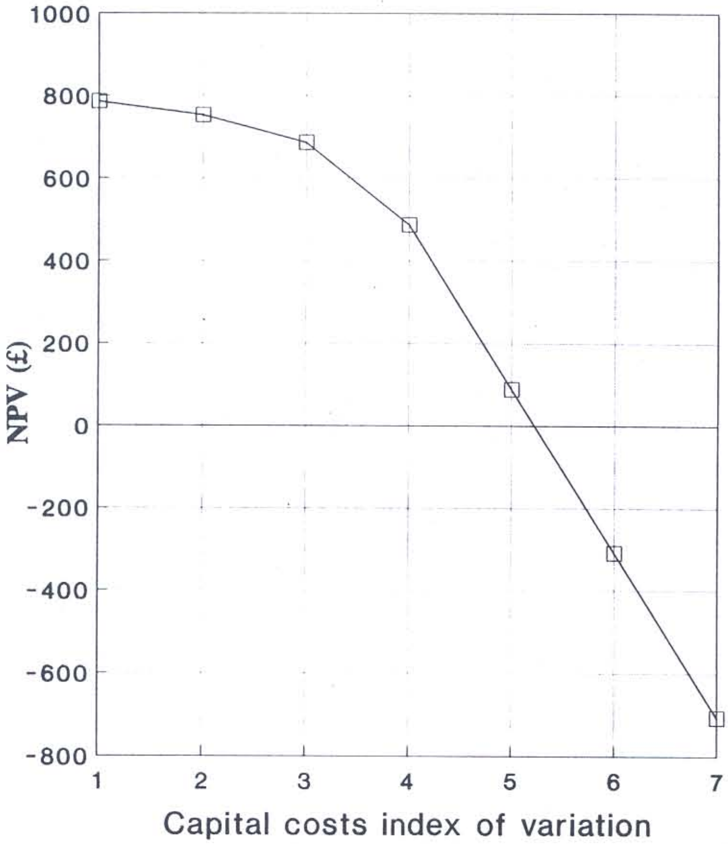

Fig. 9. Variation of solar dryer NPV with respect to capital costs. Key to capital cost indices: 1 = 1/4 x current costs; 2 =1/3 x current costs; 3 =1/2 x current costs; 4 = current costs; 5 = 2 x current costs; 6 = 3 x current costs; 7 = 4 x current costs.

6. CONCLUSION

As demonstrated in Malawi, central Africa, this dryer design can dry maize from harvest conditions of moisture to safe moisture content for storage more quickly than open air drying in good weather. The use of a PV-powered d.c. fan provides some form of passive temperature control over the drying air temperature which is desirable if efficient drying of grain to international standards of final moisture content and quality is to be achieved. Capital costs of the dryer are significantly reduced if the use of locally resourced materials is maximized. Principles that improved the dryer efficiency include:

1. A manual sun-tracking solar air heater incorporating optimized rough, blackened, sisal rope grids for improved heat transfer.
2. Photovoltaic powered air circulation that provided passive drying air temperature control.

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