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Research Application Summary

Optimization of the performance of a hybrid solar desiccant drier in grain storage systems

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Abstract

The remarkable need for alternative and renewable energy technologies is evidently an increasing feature in the developing countries. One such effort is represented in this study whose objective was to optimise the performance of a hybrid solar desiccant drier in grain storage systems. The performance of a solar collector in preconditioning the air for grain drying was investigated with the aim of developing a low cost grain drying and storage unit for small scale maize farmers. The effect of radiation concentrator convex lenses, extended surfaces (fins), lining material and exit air recirculation on the efficiency of a designed, developed and tested prototype was investigated. Effectively, perspex glazing was used to test the evacuated effect of the preventive heat losses in the collector plate due to its infrared penetration characteristics. The glazing of the collector plate was designed and moulded with a clear 2 mm acrylic material, a dome shape with a depth of 250mm onto which radiation concentrating lenses of variable focal lengths were embedded based on the length of their radiation concentration focal points and the day-arc trajectory of the sun. Additionally, the solar collector and back plate were welded with fins resulting to an increase in extended heat transfer surface area of 1.0046 m^2. A desiccant fabric was used to line the collector to trap any apparent condensation of drops of water on the inner surface of the solar collector, recirculation conduits and later during storage, a black paint was used to coat the solar collector plate. Results from point time data logger indicated highest increase of temperature and lowest relative humidity parameters of drying air within the collector combination of fins, lenses and black coated collector plate. Re-circulated exit air in desiccant lined conduits decreased the relative humidity of the air gradually more than inlet ambient air. This presents the hybrid drier as a strong candidate for a low-cost, portable, high-efficiency hybrid solar- desiccant system that can be used in grain drying to benefit both the grain and seed industry for sustained food security.

Key words: Acrylic, extended surface, re-circulation, relative humidity, solar collector, temperature

Résumé

Le besoin remarquable de technologies énergétiques alternatives et renouvelables est de toute évidence une caractéristique croissante dans les pays en développement. Un tel effort est représenté dans cette étude dont l'objectif était d'optimiser les performances un séchoir déshydratant solaire hybride dans les systèmes de stockage de céréales. Les performances d'un capteur ou collecteur solaire dans le préconditionnement de l'air pour le séchage des céréales ont été étudiées dans le but de développer une unité de séchage et de stockage des céréales à faible coût pour les petits producteurs de maïs. L'effet des lentilles convexes du concentrateur de rayonnement, des surfaces étendues (ailettes), du matériau de revêtement et de la recirculation de l'air de sortie sur l'efficacité d'un prototype conçu, développé et testé a été étudié. Effectivement, un vitrage en plexiglas a été utilisé pour tester l'effet évacué des pertes de chaleur préventives dans la plaque collectrice en raison de ses caractéristiques de pénétration infrarouge. Le vitrage de la plaque collectrice a été conçu et moulé avec un matériau acrylique transparent de 2 mm, une forme de dôme d'une profondeur de 250 mm sur laquelle des lentilles de concentration de rayonnement de focales variables ont été intégrées en fonction de la longueur de leurs points focaux de concentration de rayonnement et de la trajectoire jour-arc du soleil. De plus, le capteur solaire et la plaque arrière ont été soudés avec des ailettes, ce qui a entraîné une augmentation de la surface de transfert thermique étendue de 1,0046 m2. Un tissu déshydratant a été utilisé pour tapisser le collecteur afin de piéger toute condensation apparente de gouttes d'eau sur la surface intérieure du capteur solaire, des conduits de recirculation et plus tard pendant le stockage, une peinture noire a été utilisée pour recouvrir la plaque du capteur solaire. Les résultats de l'enregistreur de données ponctuel ont indiqué l'augmentation la plus élevée de la température et les paramètres d'humidité relative les plus bas de l'air de séchage dans la combinaison de collecteur d'ailettes, de lentilles et d'une plaque collectrice enduite de noir. L'air de sortie recyclé dans les conduits à revêtement déshydratant a diminué progressivement l'humidité relative de l'air plus que l'air ambiant d'entrée. Ceci présente le séchoir hybride comme un candidat solide pour un système hybride solaire-déshydratant à faible coût, portable et à haute efficacité qui peut être utilisé dans le séchage des grains au profit de l'industrie des grains et des semences pour une sécurité alimentaire durable.

Mots clés: Acrylique, surface étendue, recirculation, humidité relative, capteur solaire, température

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Background

Food security in developing countries is currently challenged by population increase and changing climatic conditions. Small scale farmers in the rural areas are faced by poverty and hunger whenever short and unpredictable drought periods are experienced. FAO (2011) stipulates the need for more food production (70%) to combat hunger and poverty while adapting to climate change. However post-harvest handling of the current production is a challenge especially for small scale subsistence farmers who are the majority producers in Africa.

Post-harvest management and handling of maize grain in developing countries, particularly in Kenya, is associated with unpredictable and variable weather patterns where the rainy season coincides with harvest period. Small-scale farmers in the rural areas use open – air sun drying that is often challenged by uneven drying, cracking, over-drying and losses in tonnage, drudgery of removing and returning the grain into the stores at sunset, vulnerability to predators and pest attack. In addition, spreading unshelled maize cobs on bare ground to dry exposes it to *Aspergillus flavus* which thrive on soil, thereby causing aflatoxin contamination (IFPRI, 2010). Recent weather variability causes unanticipated precipitant during harvest season which results to fluctuation in grain drying pattern occasioned by daylight open sun drying and night out/ambient rewetting due to the hygroscopic characteristic of maize kernels.

Inadequate drying and insufficient storage technology exacerbates losses through rotting, discolored grain, mold formation and eventual aflatoxin contamination as caused by elevated temperature, relative humidity and moisture content of grain. The use of mechanized technologies, electric driers and fossil fuels is expensive and inaccessible to most small-scale farmers particularly in rural areas, consequently farmers sell their maize produce immediately after harvest or green maize in the fields to ward-off these challenges, a situation that middle-men have capitalized thus losing out on the advantages of market opportunity in addition to food insecurity. The problem of solely overreliance on ineffective open sun drying system, ambient storage and subsequent aflatoxin contamination losses are the basis for an alternative need for low cost, hybrid and effective maize drying and storage system.

This research aims to apply renewable solar (green) energy in a designed and fabricated solar collector to improve the performance of an existing thermodynamic desiccant into a low cost hybrid solar -desiccant drying and storage system. Open-sun drying has no initial costs or expertise requirement making it most adopted by small-scale farmers (Sahdev and Dhingra 2016). Solar drying has widely been adopted traditionally at all levels of farming. Spreading maize over mats is the preferred method of open-sun drying in tropical and subtropical regions. However, controlling drying rate is difficult since the energy source cannot be controlled and is dependent on ambient air temperature, radiation from the sun, ambient relative humidity, wind velocity, grain layer thickness and the soil temperature below the mat (Jain and Tiwari, 2003). Apart from being labor intensive, contamination occurs due to exposure to soil, bare ground and foreign matter which could cause aflatoxin contamination (IFPRI, 2010).

Perhaps in an effort to increase the feasibility of solar dryer designs for the small-scale farmer, some researchers have made them multipurpose to cater for a range of crops. For instance, the solar tunnel drier as illustrated by Singh *et al*. (2010) was designed for drying a variety of products ranging from fruits, vegetables and even grains. There have been extensive studies on the barriers of the adoption of improved agricultural systems by small-scale farmers. In one of the studies involving solar driers, Kumar *et al*. (2014) highlights the high initial and running costs of fossil fuel-powered drying systems as one of the barriers for adoption by small-scale farmers. The researchers further noted that, while open-sun drying methods, as widely practiced by small-scale farmers in large parts of African and Asia, continue to be used, climatic conditions have a significant influence on the extent of associated losses and crop deterioration during open-sun drying. For instance, Ekechukwua and Norton (1999) observed that open-sun drying has inherent limitations including inadequate drying, possibilities of fungal attacks, insect attacks, birds and rodents, and weathering effects. Similar observations have been forwarded by Mulokozi and Svanberg (2003) regarding the loss of nutritional value of crops, and on contamination of crops by foreign materials and debris (Sadeghi *et al*., 2012).

The foregoing reasons have contributed to an increasing consensus that open-solar drying is unattractive and largely uneconomical even to the small-scale farmers (Ekechukwua and Norton, 1999). However, open-sun drying has also been associated with a mixture of benefits and limitations regarding its nutritional effect on crops. Some of the examples include findings of increased phenolic content in dried leafy vegetables (Armel *et al.,* 2015) and a case of significant reduction of provitamin A-carotenes in traditionally treated vegetables due to open-sun drying as documented by Mulokozi and Svanberg (2003). As such, it is possible to argue that following the climatic differences, sun drying could be more feasible in specific areas with reference to a particular food crop. However, in a study by McLean (1980) (as cited in Kumar *et al.,* 2014), meteorological data even for the most climatically favored regions still present open-sun drying as cumbersome, unhygienic and not always feasible. For the mentioned reasons, it is perhaps prudent to note that, firstly, open-sun drying is the cheapest alternative. However, it results in significant losses that could collectively justify the feasibility of a more capital-intensive approach. Besides, this study aims to develop a low cost efficient grain drying and storage system to benefit both the grain and seed industry. The objectives of this study were: (i) to design, develop and test prototype to optimize solar collection and (ii) to establish the effect of lenses, extended surfaces (fins) and lining material on the efficiency of the solar collector.

This research was conducted at the Food and Processing Workshop/lab in the Department of Environmental and Biosystems Engineering, University of Nairobi. Specific design activities included:

i. Calculating the collector area and dimensions
ii. Calculating the extended surface area and the number of appropriate fins
iii. Designing the appropriate glazing and collector dimensions
iv. Selecting materials for the collector glazing and absorber Plate
v. Molding and fabricating the glazing material into the required dimensions
vi. Fabricating the solar collector plate with the required extended surface(fins)
vii. Fabricating the back plate with extended surface
viii. Selecting the concentrator lenses with appropriate focal length
ix. Calculating the solar air drying chamber dimensions and select the lining materials
x. Installing the solar concentrator lenses system at maximum radiation focal points and sun trajectory
xi. Calculating the air vent dimensions
xii. Fabricating the air inlet and outlet vents at appropriate locations into the collector plate
xiii. Fabricating the recirculation conduits
xiv. Fabricating the plenum at the designed drier height
xv. Determining the pressure drop of the dry air at the plenum
xvi. Selecting a fan of the required airflow and static pressures to overcome the pressure drop.
xvii. Selecting a solar Pv module to run the selected fan in (xv) above.
xviii. Fabricating and assembling the designed prototype solar dryer for experimental drying tests

Parametric Measuring instruments

These instruments included the Sensor probe data logger and the Testo 445 multifunctional climate measuring instrument.

Sensor probe data logger: This was used to measure and record drying air parameters which include temperature, humidity and moisture levels within the drier. The specific sensor components of the data logger included:

i) ***Temperature digital sensors:*** These were used to monitor and record temperature of the drying air at various points, at the inlet-ambient temperature, system temperatures in the solar collector, Outlet to Solar Collector, Inlet of the fan, at the plenum, Outlet of the drier, and re-circulated air temperature.

ii) ***Humidity sensors:*** These were used to measure humidity of the air from a range of 0 to 100% RH of the drying air.

iii) ***Digital moisture sensors:*** These sensors were used to record the moisture levels within the system at similar points with the temperature sensors

iv) ***Digital timer sensors:*** These sensors were incorporated in the data logger programmed module to record corresponding point time data of the above conditions at every 2 minutes' interval. The output data in the form of excel spreadsheet was read from the computer. This was useful in appropriating the drying conditions of the air.

Testo 445 multifunctional climate measuring instrument: This was used to measures airflow velocity, temperature, absolute humidity, relative humidity, degree of humidity, enthalpy pressure, air quality and co.

Results and Discussion

Data from the locally made data logger sensors tested accurately for temperature and relative humidity in water, ice bath as well as ambient air conditions and thus could be used to record drying air parameter at various sections of the solar collector. Initial experimental tests indicated that concentrating convex lenses underneath the acrylic glazing had significant improvement on the temperature of the air inside the solar collector chamber. While the use of extended surface maximized heat transfers to the air, the sensor probe data loggers recorded higher values of temperature and low relative humidity compared to ambient air conditions. The effect of exit air recirculation through desiccant conduits into the collector was remarkable due to increased temperature and reduced absolute humidity compared to ambient air at inlets.

Conclusion

Results of the ongoing research indicated the potential for the application of the designed drier particularly for small scale farmers for sustained food security. Radiation concentrator convex lenses, fins and exit air recirculation conduit lined with desiccant material increased the drying effect of the solar collector.

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