The Energy Center, KNUST

ENERGY EFFICIENT RURAL FOOD PROCESSING UTILISING RENEWABLE ENERGY TO IMPROVE RURAL LIVELIHOODS (RE4Food) PROJECT

Report on Development of a 5-tonne Capacity Solar Biomass Hybrid Dryer for Drying Maize

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Summary

The issue of high post-harvest losses has been a major challenge to Ghana's agriculture modernization agenda and is a major threat to food security in the country. Among the many crops that are cultivated in the country, maize is among the major staples and is widely grown in all parts of the country. Post-harvest practices of cereal grains like maize and other cereals crops are often deeply rooted in traditional methods of preservation. It is a common practice in Ghana, where smallholder maize farmers prefer to dry their crop in the field. When field drying is not feasible, the harvested maize, either on the cob or shelled is often dried next to their home, in the village square, or along the side of the road either placed on bare ground or a tarpaulins. This method can take up to 5 days to reduce moisture content from 20% or higher to a safe storage moisture content of 12-13%. However, when harvest occurs during the rainy season, drying can extend beyond the time required to reach safe storage moisture content, and mold and insect activity can damage the crop. Thus, timely drying early in the value chain is needed to reduce post-harvest losses and preserve crop quality.

To address these challenges, a simple design of a hybrid dryer that integrates both solar and biomass energy for drying crops has been developed to provide farmers, traders, and/or processors a technology that makes drying of maize grains and other food crops possible, even during the wet season. The technology uses locally available resources and skills, making on-site construction possible. Overall dimension of the dryer is 13 × 8 × 3 m and has three drying stations each with 4 layers of drying shelves or racks with a total capacity of 5-tonnes. The dryer is coupled with a combustion chamber enclosed with a heat exchanger to provide additional heat during periods of low temperature. The exchanger is a cross flow type constructed from mild steel pipe. The overall dimension is 1.09 × 1.09 ×2.54m with brick outlay for insulation.

Introduction

In Ghana, drying grains, such as rice and maize, is one of the major postharvest problems. Farmers normally resort to direct open sun drying which requires large open space area, and very much dependent on the availability of sunshine. Such method is also susceptible to contamination with foreign materials such as dusts, litters and the grains are often exposed to birds, insect and rodents. The problem aggravates during the major season where the harvest season coincides with long rainy and cloudy weather condition. This results in delay in drying which causes discolouration, deterioration and spoilage of grains. Such grains are often rejected by consumers and may demand low selling price. Prolonged delay or intermittent drying could even cause the grains to sprout, which tender the product of no value.

To address this challenge, an innovative solar dryer with a biomass back-up heating system which is multi-purpose and utilises biomass (agro residues, timber off-cuts etc) and the sun's energy for drying grains and with the potential to dry other produce such as vegetables, roots and tubers, as well as heat sensitive produce such mushrooms is developed (see Figure for Schematic view of the dryer). The system with the back-up heating unit powered by electrical energy from solar modules can operate during the rainy season as well as at night and cloudy weather conditions. The solar biomass hybrid dryer (SBHD) mainly consists of solar tent to allow direct insolation for heat build-up and biomass furnace for burning of biomass (maize stalk, husk and cob) to supplement the heat deficiency during periods of low temperature.

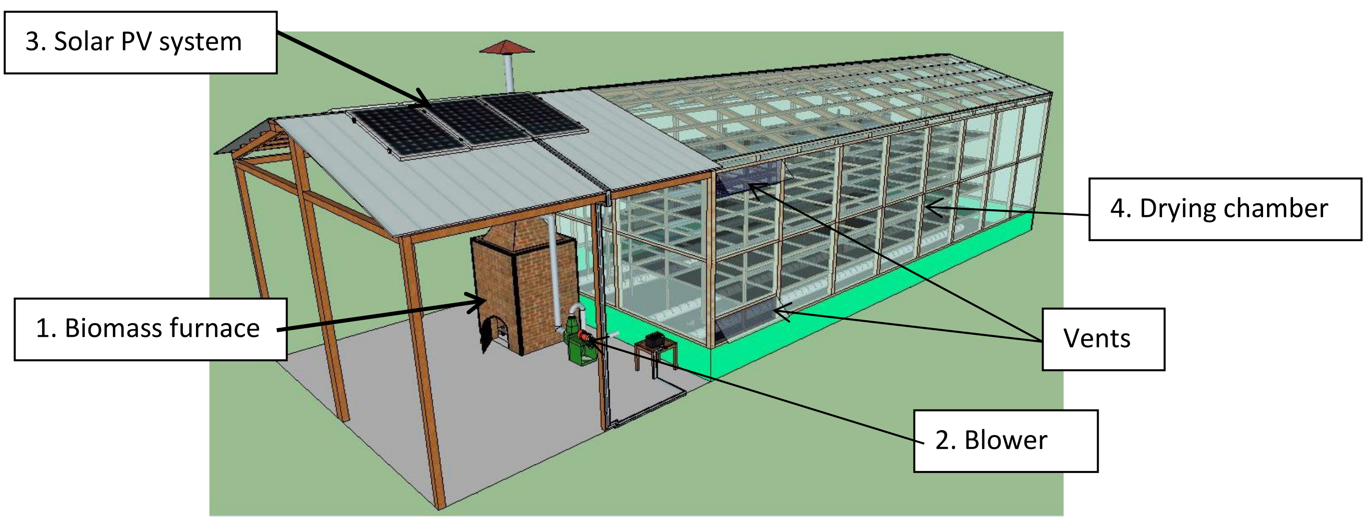

Figure 1: Schematic view of integrated solar biomass hybrid dryer

Description and Operation of the Solar Biomass Hybrid Dryer

Solar drying technologies compared to other drying methods provide preservation attributes that adds value to crops harvested at high moisture contents. Solar drying technologies are faster, more efficient, and more hygienic compared to open sun drying. It is also less expensive compared to mechanical dryers.

As shown schematically in Figure 1, the SBHD consists of the following major components: (1) a biomass furnace which burns biomass (rice husks, corn cobs, etc.) that is available in the farm; (2) an induced draft fan or blower which moves hot air from the furnace to the drying camber; (3) a solar PV system which provide the electrical energy for the blower, DC fans and bulbs (4) a drying chamber covered with transparent sheet known as Perspex. Grains to be dried are held on drying racks or shelves made of wire mesh spread across wooden beams. These racks are arranged in parallel rows with space between allowing easy access to the drying product.

The dryer is designed to operate under two basic principles. **Principle one**: the dryer operates in direct mode like a solar greenhouse dryer. A greenhouse effect is observed with the inclusion of the transparent plastic sheet. Air circulation is driven by the natural convection principle while fresh air enters the lower end of the drying chamber and escapes at the upper end. The DC fans installed in the dryer under this mode of operation also assist in the uniform distribution of the hot air in the dryer and removal of the moist air which is been discharged through the vents. Under this condition of operation, solar radiation serves as the main energy source. Heat from the solar radiation passes through the transparent cover of the dryer and is absorbed by the product. The heat generated also results in an increased temperature of the surrounding air in the dryer. Natural convection causes the heated air to rise and is thus forced through the drying trays where moisture is collected. The moist air then exits through vents located at the top of the dryer which reduces internal cabinet pressure. Consequently, ambient air is continually drawn into the dryer. The airflow in this natural convection mode of operation is established by the solar heated air becoming lighter or less dense than the ambient air. A small pressure difference is thus created by the density gradient which draws air through the collector, drying chamber, and crop. This effect increases with greater heights between the inlet and outlet vents with respect to the drying bed. The moist air is then discharged through the air vents located on the sides of the dryer above the drying chamber.

Principle 2: The mode of operation falls under a hybrid mode in terms of hot air circulation and heat transfer to the product been dried. The dryer under this condition is designed to operate with solar radiation serving as the main energy source, although biomass furnace back-up heaters are used when radiation is inadequate due to poor weather conditions and during the night so that continuous drying is made possible. During the operation of the furnace the fan or blower is used to transfer the solar-heated air from the heat exchanger to the drying chamber. Under this mode of operation one can maintain continuous ventilation and air flow through the drying chamber providing advantages of high reliability and efficiency. The solar PV system provides the electrical energy for the fans and blower for air circulation and transport of hot air from the heat exchanger into the dryer respectively. Two 12 V 200 Ah batteries serves as back-up units to store energy for the blower and the fans making it possible to construct the dryer in areas without electricity.

Technical Specifications and Construction Process

In the construction of the 5-tonne capacity SBHD, a suitable location needs to be identified and suitable materials selected and specified for fabrication with consideration given to affordable and readily available materials in the target community.

1. Selection of location to construct SBHD

Select a suitable site for the SBHD construction. Preferably the soil at the location should not be waterlogged. Ensure that all weeds, debris, stumps etc. are totally removed (Figure 2). The selected site should be a flat surface and in an open area about 30-50 m away from shadows of trees.

Figure 2: Clearing the site area of stumps, debris and weeds

Measure and clearly mark out on the cleared ground using pegs, the specific land area for the SBHD construction depending on the size or overall dimension of the dryer (e.g. 13m × 8 m).

Figure 3: Measurement and marking out of land area for SBHD construction

Follow up with further land leveling activities (Figure 4) to fill in holes and cut off mounds so as to have a very level ground. Where necessary, cut the land to ensure a level surface is obtained.

Figure 4: Leveling out of land area for SBHD construction

2. *Laying of foundation and platform to construct SBHD*

Per the mark out dimensions on the ground, lay blocks (Figure 5) to set the foundation and overlay it with concrete cast to prepare a platform for the construction of the SBHD. After casting, lay about one or two layers of blocks (Figure 6) to set a boundary layout to prevent run-off water during raining from entering the structure.

Figure 5: Setting of foundation and overlaying with concrete cast

Figure 6: Laying of blocks on concrete platform

3. Mounting of Structure Pillars and Truss Unit

The main structural frame (Figure 7) of the dryer is made of treated hard wood beams (e.g., *Teak*, *Mahogany*, *Odum* etc.) and is of square shape with dimension 0.3 × 0.3 m or circular shape of diameter 0.1 m. The main frame and pillar beams are set in the concrete foundation base at 0.5 m depth. For a 5-tonne capacity SBHD, about 25 pieces of such wood logs or beams are required. The truss to support the roof of the structure is mainly formed from wood sizes of 0.05m × 0.1m and 0.05m × 0.15m. It is important to select very durable wood materials that are treated against termites attack for the truss system.

Figure 7: Mounted structural pillars and roof truss system

4. ***Mounting of drying racks or shelves***

The drying racks or shelves are made of nylon and wire mesh spread across wooden beams of size 1.2 m × 0.9m × 0.05 m. These racks are arranged in opposite rows with about 1.22m space between allowing easy access to the drying product. About 120 of such shelves forming 4 drying levels with spacing of about 0.61m between each level are required for a 5-tonne capacity SBHD. The shelves are held with nails on 0.05m × 0.1m wood beams to keep the shelves in position and also provide the needed joint support for the shelves and product load. The shelves are inclined at about 30^{o} to allow easy flow of grains into the discharge cutters after drying. A space of about 0.61m is allowed between the shelves and the boundary blocks as walk way around the shelves and also for easy access for maintenance works.

Figure 7: Mounting of drying racks

5. Overlaying SBHD with transparent plastic sheets (Perspex)

The dryer is covered with 3 mm thick acrylic, Perspex or translucent plastic sheet material that allows heat and light diffusion into the structure. The transparent plastic sheet is very delicate and should be cut with care to the required sizes to fit the roof and the sides of the SBHD (Figure 8). The sheets should be fixed to overlap at the ridge and the base of the boundary walls to avoid rain water seepage into the dryer. One should roof the SBHD first before the sides to allow some comfort for the workers due to heat stress.

Figure 8: Overlaying of SBHD with Transparent sheet

The dryer has one main entrance, made of a wood-framed door covered by Perspex sheet. Side vents measuring about 1.22 m × 03 m are installed on both sides of the dryer to aid air circulation. These are completely covered by anti-insect, 40-inch mesh netting. All roll-up vents are covered by plastic sheets.

6. Construction of Biomass Furnace

When the drying process coincides with long rainy and cloudy weather condition, delay in drying may cause deterioration and spoilage of grains which will demand low selling price. Prolonged delay in drying could even cause the grains to sprout, which will tender the product of no value. The biomass furnace is mainly made of heat exchangers insulated with Rockwool and sits in a bricked wall (Figure 9). The furnace is attached to the dryer to provide additional heat during such periods to support the drying process. All types of biomass (e.g., agro residues) can be used as fuel source to generate the heat required. The furnace is mounted at the back of the dryer about 0.61m to 0.91m away. The heat exchanger is constructed from 0.08m diameter by 1.09m length mild steel pipes. The pipes are spaced at about 0.2m and designed in the form of a pyramid with a chimney on top of the heat exchanger to trap smoke and flue gases during combustion. The exchanger can be formed and mounted at site. ***Step 1***: Cut the mild steel pipes to dimension and weld to form the composite exchanger (Figure 8). ***Step 2***: Lay high density refractory bricks (HDRB) across and directly under the base pipes to support the weight of the heat exchanger. ***Step 3***: Wrap the Rockwool around the pipes to provide insulation (Figure 9). ***Step 4***: Lay bricks to enclose the heat exchanger to serve as the final insulation unit (Figure 9).

Figure 8: Construction of biomass furnace at site

The furnace has overall dimension of 2.71m high by 1.46m width. The combustion chamber (Figure 10) consists of a fire grate made of a 10-mm thick mild steel plate which burns 20 to 25 kg of biomass (rice husks, corn cobs, coconut husks, wood wastes, etc.) by direct combustion with excess air.

Figure 9: Biomass Furnace showing heat exchanger unit

Figure 10: Biomass furnace showing combustion chamber

Air is heated with the help of a high air volume blower fan that draws warm air from the dryer into the bricked-in heat exchanger that surrounds the biomass burner. Heated air is re-introduced into the bottom of the dryer by air distribution ducts placed beneath the drying racks (Figure 11). Make-up air can be drawn into the heat exchanger to control the mix with warm air from the dryer. The power required to operate the blower fan (Figure 12) draws a sufficiently low electric current that can be supplied by a photovoltaic system (Figure 13). It is designed to provide the power required to run a 2Hp blower, installed 12W DC fans in the dryer and other accessories like DC bulbs that provide light for drying in night.

Figure 11: Hot air distribution duct inside dryer

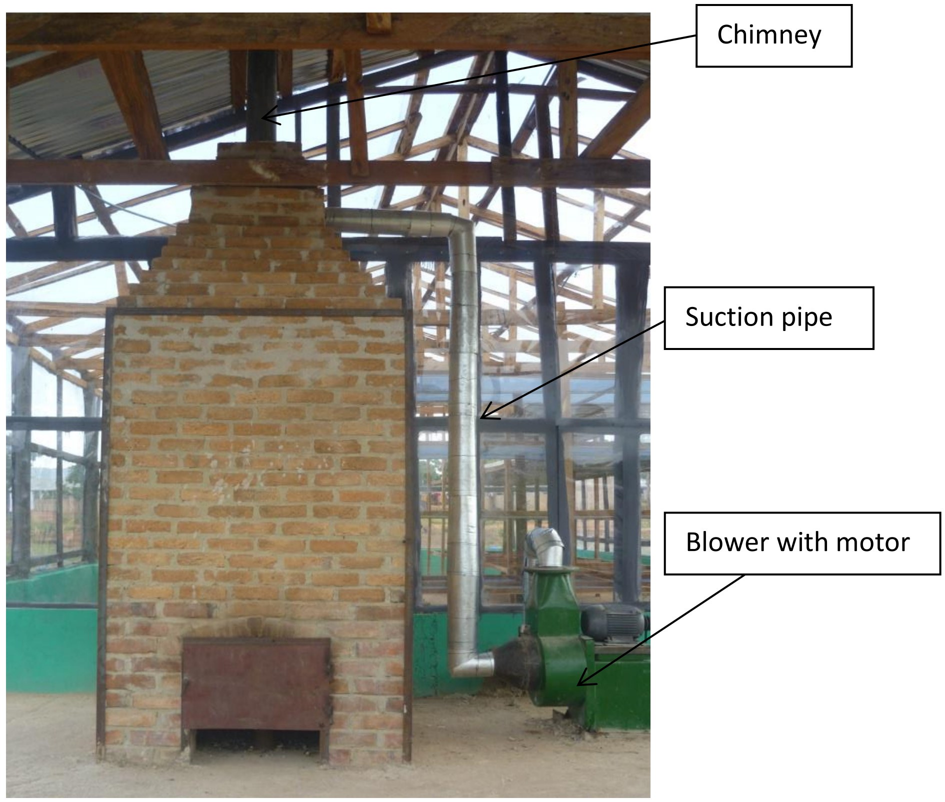

Figure 12: Biomass furnace with blower

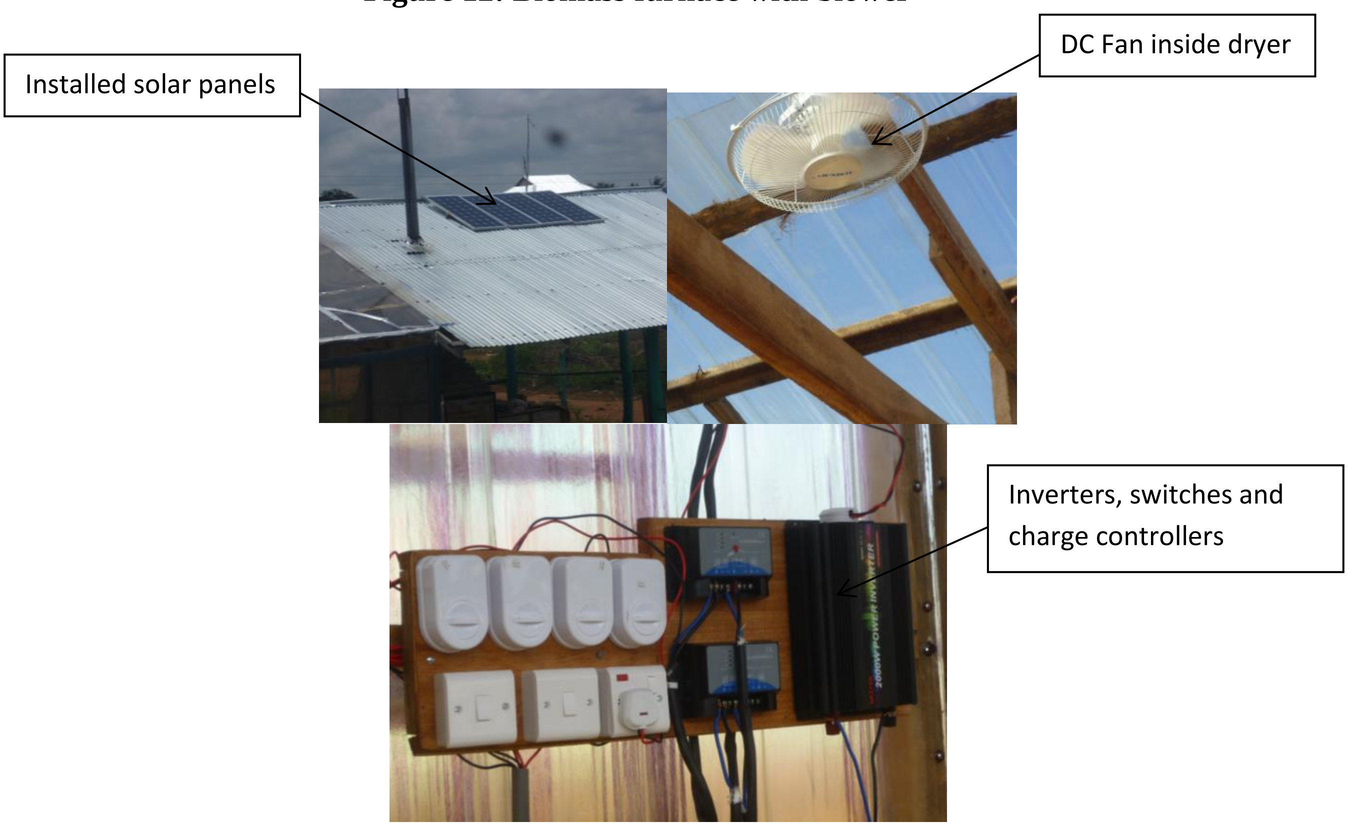

Figure 12: Photovoltaic System

Concluding remarks

Construction of the solar biomass hybrid dryer was successfully completed in 2015 using locally available materials. With overall dimension of 13m × 8m × 3m, the dryer can be used to dry about 40-50 bags of maize over a period of 8-10hrs depending the initial moisture content of the harvested grains. The design of the biomass furnace which uses agro-waste fuel such as rice husks, corn cobs, wood wastes, etc. provides the advantage of no odour from smoke and discolouration of grains when drying. The motor of the blower fan does not run on electricity, diesel or gas. There is low power consumption as the power to run the blower is from the solar PV system. The dryer can be easily built by users themselves thus saving cost on investment.