JENRM, Vol. 4, No. 3, 62-69, 2017
Research Article

A safe and clean way of reducing the rate at which farm produce deteriorate after harvest

S. S. Anobil*

Abstract
Most of the food crops harvested in Ghana during the growing season of that particular crop are abundant and so there is the need to device a means of storing the food to prevent them from deteriorating in order to prevent hunger and scarcity of crop after the growing season. In general, farmers have a problem in having their crops dried fast, efficiently, economically and environmentally well. Drying on the ground by the sun is recently the most used method. Most farmers cannot afford to import expensive mechanical drying equipment, which is either electricity or diesel engine driven, with the additional financial burden of maintenance, fuel, electricity and other running expenses. Apart from the environmental problems. Many more farmers will be able to increase their output if a relatively cheap solar dryer for crops is made available with the additional benefit of relatively low running expenses. The success of such equipment would depend upon the final cost of the solar dryer, each farmer's financial situation, on the bank and the manufacturer, and in some cases, donor agencies would become some of the important aspects of farming. A very large proportion of the food products in developing countries like Ghana is destroyed before they are shipped to the market. Some food products are dried before they are shipped to the market some food products are still being put out on the ground and in the sun. This is however, a very slow method of drying and often take many days and also the products are not uniformly dried. Food products are exposed bacteria attack which may make them dangerous to consume. Crops are exposed to insects and fungus attack and polluted by dust. Based on preliminary investigations under controlled conditions of drying experiments, a natural convection solar dryer was designed and constructed to dry mango slices. These considerations helped in realizing the importance of designing and manufacturing after presenting the results of calculations of the design parameters. A minimum of $16.8m^2$ solar collector area is required to dry a batch of 100kg sliced mango (195.2kg fresh mango at 51.22% pulp) in 20hours (two days drying period). The initial and final moisture content considered were 81.4% and 10% wet basis, respectively. The average ambient conditions are 30^oC air temperature and 15% relative humidity with daily global solar radiation incident on horizontal surface of about 20MJ/m2/day. The weather conditions considered are of Khartoum, Sudan. A prototype of the dryer is so designed and constructed that has a maximum collector area of 1.03m2. This prototype dryer will be used in experimental drying tests under various loading conditions. [1] (Solar drying in Ghana final report Soren Ostergaard Jensen: Danish technological institute July 2002).

Keywords
growing season, solar radiation, ambient conditions, exposed, convection drying experiments.

*Department Of Mechanical And Manufacturing Engineering, University Of Energy And Natural Resources Email: sarkwaanobilsamuel@yahoo.com
***Corresponding author**: S. S. Anobil Email: sarkwaanobilsamuel@yahoo.com

Contents

1. Introduction

Sun drying is still the most common method used to preserve agricultural products in most tropical and subtropical countries. However, being unprotected from rain, wind-borne dirt and dust, infestation by insects, rodents and other animal, products may be seriously degraded to the extent that sometimes become inedible and the resulted loss of food quality in the dried products may have adverse economic effects on domestics and international markets. Some of the problems associated with open-air sun drying can be solved through the use of a solar dryer which comprises of collector, a drying chamber and sometimes a chimney (Madhlopa et al., 2002).The conditions in tropical countries make the use of solar energy for drying food practically attractive and environmentally sound.

Dryers have been developed and used to dry agricultural products in order to improve shelf life (Esper and Muhlbauer, 1996). Most of these either use an expensive source of energy such as electricity (El-Shiatry et al., 1991) or a combination of solar energy and some other form of energy (Sesay and Stenning, 1996). Most projects of these nature have not been adopted by the small farmers, either because the final design and data collection procedures are frequently inappropriate or the cost has remained inaccessible and the subsequent transfer of technology from researcher to the end user has been anything but effective (Berinyuy, 2004).

The total cultivated area and production of mango in Sudan, year 2003, was estimated to be about 51926 feddan (21,809 hectares) and 442,330 tonnes, respectively (Ministry of Agriculture, 2004). Mangoes are popular fruits on the world market because of their unique and attractive flavour, colour and nutritional value. In spite of its excellence, the perishable nature of this fruit and its short harvest season severely limit utilization, consequently mango has not been developed as commercial and export crop. Drying may be an interesting method in order to prevent fresh fruit deterioration. There is spoilage of fruits and other fresh foods that could be preserved using drying techniques in Sudan and other developing countries. Seasonal fruits like mangoes are not presently dried for export, or for local consumption during period of scarcity.

Large quantities of the mango fruit spoil under parent tree in remote areas in spite of the enormous potential for the utilization of solar energy for drying and other applications. It is, therefore, envisaged that the design of a simple solar dryer could contribute greatly in solving this problem. Solar dryers are usually classified according to the mode of air flow into natural convection and forced convection dryers. Natural convection dryers do not require a fan to pump the air through the dryer. Therefore research efforts will be focused on designing and constructing a simple natural convection dryer. Since the rural or remote areas of Sudan are not connected to the national electric grid and remote areas of Sudan facing energy crisis, especially

West Darfur state. The use of solar technology has often been suggested for the dried fruit industry both to reduce energy costs and economically speed up drying which would be beneficial to final quality (Lambert et al., 1980). El- Shiatry et al. (1991) dried grapes, okra, tomato and onion using solar energy. They concluded that drying time reduced significantly resulting in a higher product quality in terms of colour and reconstitution properties. They also believe that as compared to oil or gas heated dryers, solar drying facilities are economical for small holders, especially under favourable meteorological conditions. [2] EL- Amin Omda Mohamed Akoy a, Mohamed Ayoub Ismail b, El-Fadil Adam Ahmed c and W. Luecke d.

2. Literature Review

Crop drying is the most energy consuming process in all processes of farming. The purpose of drying is to remove moisture from the agricultural produce so that it can be processed safely and stored for a longer period of time. Crops are also dried before or during storage, by forced circulation of air, to prevent spontaneous combustion by inhibiting fermentation. It is estimated that 20% of the world‘s grain production is lost after harvest because of inefficient handling and poor implementation of post-harvest technology, [3] Hartman‘s (1991). Grains and seeds are normally harvested at a moisture level between 18% and 40% depending on the nature of crop. These must be dried to a level of 7% to 11% depending on application and market need. Once a cereal crop is harvested, it may have to be stored for a period of time before it can be marketed or used as feed. The length of time a cereal can be safely stored will depend on the condition by which it was harvested and the type of storage facility being utilized. Grains stored at low temperature and moisture contents can be kept in storage for longer period of time before its quality will deteriorate. In direct solar dryers the air heater contains the grains and solar energy which passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed. However, in indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or the roof.

Energy is important for the existence and development of human kind and is a key issue in international policy. To reduce the impact of conventional energy sources on the environment, much attention should be paid to the development of new energy and renewable energy resources. Solar energy, which is environment friendly, is renewable and can serve as a sustainable energy source. Hence, it will certainly become an important part of the future energy structure with the increasingly drying up of the terrestrial fossil fuel. However, the lower energy density and seasonal doing with geographical dependence are the major challenges in identifying suitable applications using solar energy as the heat source. Consequently, exploring high efficiency solar energy concentration technology is necessary and realistic. Solar energy is free, environmentally clean, and therefore is recognized as one of the most promising alternative energy recourses options. In near future, the large-scale introduction of solar energy systems, directly converting solar radiation into heat, can be looked forward. However, solar energy is intermittent by its nature; there is no sun at night. Its total available value is seasonal and is dependent on the meteorological conditions of the location. Unreliability is the biggest retarding factor for extensive solar energy utilization. Of course, reliability of solar energy can be increased by storing its portion when it is in excess of the load and using the stored energy whenever needed. Solar drying is a potential decentralized thermal application of solar energy particularly in developing countries. However, so far, there has been very little field penetration of solar drying technology. In the initial phase of dissemination, identification of suitable areas for using solar dryers would be extremely helpful towards their market penetration. [3] (A. Madhlopa a,*, G. Ngwalo: Solar dryer with thermal storage and biomass-backup heater)

3. Materials

Materials Used for fabrication of the solar dryer the following materials were used for the construction of the efficient solar dryer:

- Wood
- Glass
- Galvanized steel (GS)
- Nails and glue
- Hinges and handle
- Paint (black and grey)
- Copper tubes
- Mesh wire
- Wheels

4. Method

4.1 Deign considerations

1. Temperature The minimum temperature for drying food is 30°C and the maximum temperature is 60°C, therefore. 45°C and above is considered average and normal for drying vegetables, fruits, roots and tuber crop chips, crop seeds and some other crops .

2. Design The design was made for the optimum temperature for the dryer. T0 of 60°C and the air inlet temperature or the ambient temperature T1 = 30°C (approximately outdoor temperature).

3. Air gap It is suggested that for hot climate passive solar dryers, a gap of 5 cm should be created as air vent (inlet) and air passage.

4. Glass or flat plate collector It suggested that the glass covering should be 4-5 m thickness. In this work, 4mm thick transparent glass was used. He also suggested that the metal sheet thickness should be of 0.8 − 1.0 m thickness; here a Galvanized steel of 1.0mm thickness was used. The glass used as cover for the collector was $103 \times 100cm^2$.

5. Dimension It is recommended that a constant exchange of air and a roomy drying chamber should be attained in solar food dryer design, thus the design of the drying chamber was made as spacious as possible of average dimension of $100 \times 103 \times 76cm^3$ with air passage (air vent) out of the cabinet of $90 \times 10cm^2$. The drying chamber was roofed with glass of $100 \times 103cm^2$. This is to keep the temperature within the drying chamber fairly constant due to the greenhouse effect of the glass.

6. Dryer Trays $1cm^2$ Net was selected as the dryer screen or trays to aid air circulation within the drying chamber. Two trays were made having wooden edges. The tray dimension is 96 × 98 cm of 2.5cm × 2.5cm wooden sticks used as frame. The design of the dry chamber making use of GS sheet wall sides and a glass top (tilted) protects the food to be placed on the trays from direct sunlight since this is undesirable and tends to bleach colour, removes flavour and causes the food to dry unevenly. [4] (R. Vidya Sagar Raju, R. Meenakshi Reddy, and E. Siva Reddy: Design and Fabrication of Efficient Solar Dryer)

4.2 Design calculations

To carry out design calculations and size of the dryer, the design conditions applicable to Khartoum are required. The conditions and assumptions summarized in Table 1 are used for the Design of the mango dryer. Amount of moisture to be removed from a given quantity of wet mango slices to bring the moisture content to a safe storage level in a specified time.

: Mw = mp (Mi – Mf) / (100- Mf) (1)

Where: mp is the initial mass of product to be dried, kg; Mi is the initial moisture content, % wet basis and Mf is the final moisture content, % wet basis.

: Ii-Final or equilibrium relative humidity: Final relative humidity or equilibrium relative humidity was calculated using sorption isotherms equation for mango given by Hernandez et al (2000) as follows:

: aw = 1- exp [-exp (0.914+0.5639lnM)] (2)

Where: aw = water activity, decimal M = moisture content dry basis, kg water/kg dry solids

aw = ERH/100 (3)

: Iii-Quantity of heat needed to evaporate the H_2O: The quantity of heat required to evaporate the H_2O would be:

Q = mw x hfg (4)

Where: Q = the amount of energy required for the drying process, kJ Mw = mass of water, kg hfg = latent heat of evaporation, kJ/kg H_2O The amount needed is a function of temperature and moisture content of the crop. The latent heat of vaporization was calculated using equation given by Youcef-Ali et al. (2001) as follows:

hfg = 4.186*103(597-0.56(Tpr)) (5)

Where: Tpr = product temperature, ºC Moreover, the total heat energy, E (kJ) required to evaporate water was calculated as follows:

E = m‘ (hf -hi) td (6)

Where: E = total heat energy, kJ M‘ = mass flow rate of air, kg/hr. hf and hi = final and initial enthalpy of drying and ambient air, respectively, kJ/kg dry air. td = drying time, hrs. The enthalpy (h) of moist air in J/kg dry air at temperature T (ºC) can be approximated as (Brooker et al., 1992):

: h = 1006.9T +w [2512131.0 +1552.4T] (7)

Iv- Average drying rate : Average drying rate, mdr, was determined from the mass of moisture to be removed by solar heat and drying time by the following equation:

mdr = mw/ td (8)

The mass of air needed for drying was calculated using equation given by Sodha et al. (1987) as follows:

M‘= mdr / [wf –wi] (9)

Where: mdr = average drying rate, kg/hr Wf – wi, final and initial humidity ratio, respectively, kg H_2O/kg dry air From the total useful heat energy required to evaporate moisture and the net radiation received by the tilted collector, the solar drying system collector area Ac, in m2 can be calculated from the following equation:

: $AcI\eta$ = E = m‘ (hf -hi) td (10)

Therefore, area of the solar collector is:

Ac = E/$I\eta$(11)

Where E is the total useful energy received by the drying air, kJ; I is the total global radiation on the horizontal surface during the drying period, kJ/m^2 and η is the collector efficiency, 30 to 50% (Sodha et al., 1987). Volumetric airflow rate, VA was obtained by dividing ma by density of air which is 1.2 kg/m^3

: Air vent dimensions: The air vent was calculated by dividing the volumetric airflow rate by wind speed:

Av = Va/Vw (12)

Where Av is the area of the air vent, m2, Vw wind speed, m/s.The length of air vent , Lv, m, will be equal to the length of the dryer. The width of the air vent can be given by:

Bv = Av/Lv (13)

Where Bv is the width of air vent, m

: Required pressure:

Velocity = Va/A

Va = volumetric flow rate m^3/sec. The pressure difference across the mango slices bed will be solely due to the density difference between the hot air inside the dryer and the ambient air. Air pressure can be determined by equation given by Jindal and Gunasekaran (1982):

: P = 0.00308 g (Ti - Tam) H (14)

Where: H is the pressure head (height of the hot air column from the base of the dryer to the point of air discharge from the dryer), m; P is the air pressure, Pa; g is the acceleration due gravity, 9.81m/s^2; Tam is the ambient temperature, C. The prototype solar dryer was sized to have a minimum area of 1m2 to be used in experimental drying tests.

Fruits	%water content
Banana	74
Orange	87
Peach	88
Pear	84
pineapple	87
Plum	85
watermelon	92

Vegetable	%water content	vegetable	%water content
broccoli	91	potato	79
cabbage	93	radish	95
Carrot	87	spinach	92
cauliflower	92	tomato	94
cucumber	96	eggplant	92
peas	79		

Figure 1

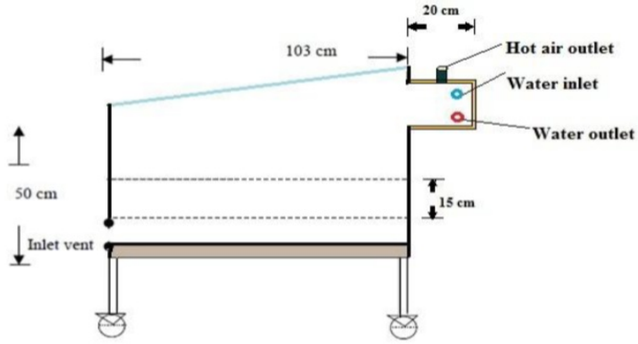

Figure 2

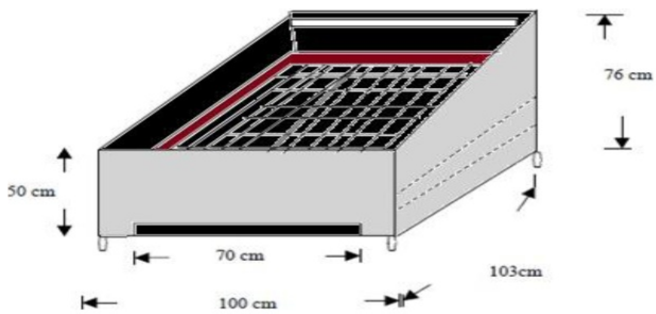

Figure 3

5. Discussion

An indirect type natural convection solar dryer has been designed and constructed with an integrated thermal mass and a biomass-backup heater. Simple materials and skills were employed to build it. The dryer was tested in three modes of operation (solar, biomass and solar–biomass), using fresh pineapples under different weather conditions. Results show that the thermal mass stored part of the heat from both solar and biomass air heaters, thereby moderating temperature fluctuations in the drying chamber and reducing wastage of energy. Relatively high plenum temperatures were attained when the door to the biomass burner was kept open during the combustion period. It was possible to dry pineapple slices using solar energy only under favorable meteorological conditions. The solar mode of operation was slowest in drying the samples, with the solar–biomass mode being fastest under the prevailing meteorological conditions. Drying proceeded successfully even under very bad weather conditions in the solar–biomass mode of operation. Final moisture contents were within acceptable limits for safe storage of the dried pineapples which were also of high nutritional quality. The rate of drying was not uniform across the trays. Consequently, there is need for interchanging them during drying to achieve a uniformly dried product. Reverse thermo siphoning was observed in the solar chimney during nocturnal drying, which reveals the need to re-visit the design of solar chimneys fitted on solar dryers developed for both diurnal and nocturnal free-convection drying of crops. The moisture- pickup efficiency of the system was most satisfactory in the solar mode of operation. It appears that the solar dryer is suitable for preservation of pineapples and other fresh foods. Nevertheless, the following further improvements are suggested: (a) transparent insulation of the exterior surface of the solar chimney (or re-circulation of flue gas around the solar chimney) to avert reverse thermo siphoning at night or during periods of low insolation, and (b) optimization of the system.

6. Analysis

Cost Economics, of Food Solar dryer System enterprises are worked out for fruits and vegetables. 1 Million For one unit of 10 dryers. It can transact 10 tons of fruits or fruit bars in dehydrated form. This is an excellent income and profitable venture in rural Saudi Arabia. The cost benefit analysis of our dryers indicates that a commercial venture of a project with 10 solar dryers will give the payback period of 2 - 2½ years. The profitability of the technology in terms of employment potential and income generation is established and acceptability of the product in the market is evaluated from the proven market demand. Our expectation about the feasibility of the technology for rural employment has been realized.

7. Findings

From the test carried out, the following conclusions were made. The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The product inside the dryer requires less attentions, like attack of the product by rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer was used to dry Potato, it can be used to dry other crops like yams, cassava, maize and plantain etc. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower to that of a mechanical dryer. Also from the test carried out, the simple and inexpensive mixed-mode solar dryer was designed and constructed using locally sourced materials. The hourly variation of the temperatures inside the cabinet and air-heater are much higher than the ambient temperature during the most hours of the day-light. The temperature rise inside the drying cabinet was up to 24^oC (74%) for about three hours immediately after 12.00h (noon). The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product.

8. Results

For the first-day efficiency, it is seen that the solar mode of operation exhibits the highest mean value, with the biomass mode showing the lowest value. This is probably due to the high heat losses through the flue gas, which results in a lower efficiency than that for the solar mode of operation. For the final-day efficiency, it is again observed that the system efficiency is highest (15%), lowest (11%) and intermediate (13%) in the solar, biomass and solar–biomass modes of operation respectively. Brenndorfer et al. (1985) reports that typical efficiency values for a natural convection solar dryer are 10–15%. Bena and Fuller (2002) report efficiency values of 22%, 6% and 8.6% for a direct type free-convection solar dryer operated in the solar, biomass and solar–biomass modes of operation respectively. Consequently, the performance of the present solar dryer is satisfactory natural convection solar air heating system. For nocturnal operation, it was observed that there was condensate on a small portion of the absorber area directly below the air inlet to the solar chimney. This was attributed to reverse flow at night when the chimney became cold and acted as a condenser for the warm (and humid) air rising up from the drying bed. In view of this, the entrance to the solar chimney was blocked with card board papers at sunset (with open air vents), and opened at sunrise (with closed air vents) to avert reverse thermo siphoning. This approach proved to be effective.

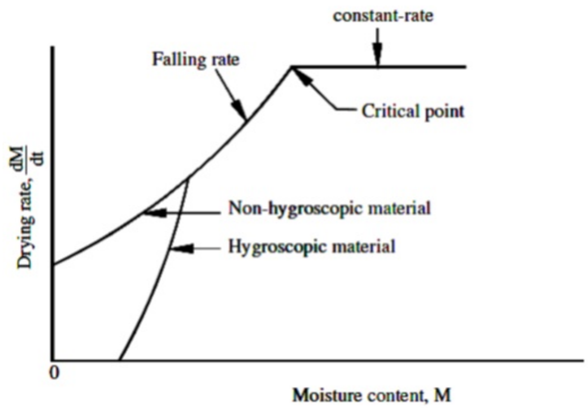

Figure 4

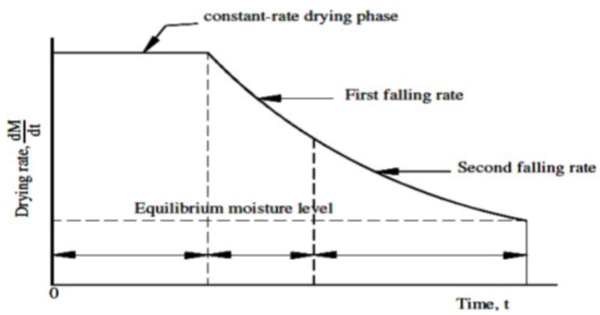

Figure 5

9. Recommendations

The performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the drying time, and probably storage of heat energy within the system by increasing the size of the solar collector. Also, meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them. The present work can be extended by arranging copper tubes to the side walls of dryer to recover heat from the side walls. Double slope passive solar dryer can be fabricated to attain higher efficiencies. In place of heat exchanger (water) phase change material can be placed to recover total waste heat coming from the dryer.[6] (Abdulelah Ali Al-Jumaah, Abdullah Mohamed Asiri, Mohamed Fadil Alshehri,Ahmed Mohamed Deash, Fahd Minajy Al-Hamzi: DESIGN AND CONSTRUCTION OF A SOLAR DRYING SYSTEM FOR FOOD PRESERVATION)

Nomenclature

A area (m2)

c specific heat capacity of air at constant pressure

(J kg_1 K_1)

Cv calorific value of biomass (J kg_1)

D diameter or hydraulic diameter (m)

f friction factor in burner enclosure (dimensionless)

hc convective heat transfer (W m_2 K_1)

hi inlet air specific enthalpy (J kg_1)

hp plenum air specific enthalpy (J kg_1)

hr radiative heat transfer (W m_2 K_1)

hwg latent heat of vaporization of water (J kg_1)

H vertical height (m)

K coefficient of pressure loss (dimensionless)

k coefficient of heat conductivity (W m_2 K_1)

I instantaneous solar irradiation (W m_2)

L length (m)

m mass (kg)

_m

fluid flow rate (kg s_1)

M moisture content (%)

Nu Nusselt number (dimensionless)

DP pressure drop (N m_2)

Q thermal energy (J)

Q_ rate of heat transfer (W)

Re Reynolds number (dimensionless)

Rv retention of vitamin C (%)

T temperature (K)

DT difference between ambient and component air temperature (K)

ur reference velocity of drying air (m s_1)

U velocity of system drying air (m s_1)

UL overall heat transfer coefficient from chimney

(W m_2 K_1)

vr reference velocity of flue gas (m s_1)

vs specific volume of air (m3 kg_1)

V velocity of system flue gas (m s_1)

Vd concentration (db) of vitamin C in solar-dried

sample (kg/kg of pineapple)

Vw concentration (db) of vitamin C in fresh sample

(kg/kg of pineapple)

W humidity ratio (kg/kg of dry air)

x thickness (m)

Z height above drying bed as shown in Fig. 5 (m)

Greek symbols

b coefficient of thermal expansion (K_1)

/ relative humidity (%)

g efficiency of dryer (dimensionless or %)

m kinematic viscosity (m2 s_1)

q density (kg m_3)

s time (s)

Subscripts

1 initial

2 final

a air/ambient

ab absorber

as interface between absorber plate and rock bed

at absorber top part

b biomass

bo bottom concrete base

bu burner

co collector

da drying air

db dry basis

dd drying bed

dr drum

du duct

fc flue gas chimney

fe flue gas exit from rectangular duct

fg flue gas

gr ground/soil

i inlet

ip initial pineapple

p plenum

pm mean plenum

r radiative

ra resistance to drying air flow

rf resistance to flue gas flow

s rock storage bed

sc solar chimney

sr stored

st rock storage bottom

t thermal

ta thermal buoyancy of drying air

tf thermal buoyancy of flue gas

tm thermal mass

ve vermiculite

w moisture/water

wa wall

wb wet basis

wp wet bulb in plenum

10. Conclusion

Solar radiation can be effectively and efficiently utilized for drying of agricultural produce in our environment if proper design is carried out. This was demonstrated and the solar dryer designed and constructed exhibited sufficient ability to dry agricultural produce most especially food items to an appreciably reduced moisture level. Locally available cheap materials were used in construction making it available and affordable to all and sundry especially peasant farmers. This will go a long way in reducing food wastage and at the same time food shortages, since it can be used extensively for majority of the agricultural food crops. Apart from this, solar energy is required for its operation which is readily available in the tropics, and it is also a clean form of energy. It protects the environment and saves cost and time spent on open sun drying of agricultural produce since it dries food items faster. The food items are also well protected in the solar dryer than in the open sun, thus minimizing the case of pest and insect attack and also contamination.

However, the performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the drying time and probably storage of heat energy within the system. Also, meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them. A solar dryer is designed and constructed based on preliminary investigations of drying under controlled conditions (laboratory dryer).

The constructed dryer is to be used to dry vegetables under controlled and protected conditions. The designed dryer with a collector area of 1m2 is expected to dry 20kg fresh vegetables from 89.6% to 13% wet basis in two days under ambient conditions during harvesting period from February to March. A prototype of the dryer with 1.03m2 solar collector area was constructed to be used in experimental drying tests. Along with this the water heating system is also employed to the dryer to recover the waste heat getting from the dryer. Hence the practical usage of dryer is greatly increased by employing the water heating system along with dryer. [5] (Oguntola J. ALAMU1,a, *Collins N. NWAOKOCHA2,b and Olayinka ADUNOLA1:Mechanical Engineering Department, University of Agriculture, Abeokuta, Nigeria. 2Mechanical Engineering Department, Olabisi Onabanjo University, Ago-Iwoye, Nigeria. E-mail: atolasum@yahoo.com, bcolneks2000@yahoo.com.)

References

[1] EL-Amin Omda Mohamed Akoy a, Mohamed Ayoub Ismail b, El-Fadil Adam Ahmed c and W. Luecke d: Design and Construction of a Solar Dryer for Mango Slices: a Dept. of Agric. Eng., Faculty of Agriculture, University of Zalingei, Zalingei, Sudan.

[2] Soren Ostergaard jesen: solar drying in Ghana final report: Danish technological institute July 2002.

[3] Gom Dorji: Solar drier model development methods and working: Royal University of Bhutan

[4] R. Vidya Sagar Raju1, R. Meenakshi Reddy, E. Siva Reddy: Design and Fabrication of Efficient Solar Dryer: School of Mechanical Engg, R.G.M.C.E.T, Nandyal, A.P.A. Madhlopa a,*, G. Ngwalo: Solar dryer with thermal storage and biomass-backup heater: Department of Physics and Biochemical Sciences, Malawi Polytechnic, P/Bag 303, Blantyre 3, Malawi

[5] Oguntola J. ALAMU, Collins N. NWAOKOCHA and Olayinka ADUNOLA: Design and Construction of a Domestic Passive Solar Food Dryer: 1Mechanical Engineering Department, University of Agriculture, Abeokuta, Nigeria.

[6] Abdulelah Ali Al-Jumaah Abdullah Mohamed Asiri Mohamed Fadil Alshehri Ahmed Mohamed Deash Fahd Minajy Al-Hamzi: DESIGN AND CONSTRUCTION OF A SOLAR DRYING SYSTEM FOR FOOD PRESERVATION: College of Engineering Mechanical Engineering Department Jazan University 2006.