International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

A Comparative study of commonly used Solar Dryers in India

Garima Tiwari[a], V. K. Katiyar[a], Vivek Dwivedi[a], A. K. Katiyar[b] and C. K. Pandey[b*]

[a]Brahmanand Post Graduate College, the Mall, Kanpur-208004,India
[b]I.E.T, Sitapur Road Lucknow-226021, India

Accepted 02 August 2013, Available online 05 August 2013, **Vol.3, No.3 (August 2013)**

Abstract

The global concerns about energy consumption and environmental sustainability raise the aspiration of applying solar energy to agriculture. Therefore, an attempt has been made to study the performance of different kinds of popular solar dryers for plain region, India and compared. For the purpose of comparison, certain criteria and crops have been selected and dryers performance were tested on these criteria. Solar Tunnel dryer and solar hybrid dryer are found to be more suitable as for as drying time and the quality of dried crop is concerned.

Keywords: *Solar energy; crops; solar tunnel; ambient temperature.*

1. Introduction

Drying crop products by solar energy is of great interest, especially in the plain region, where solar energy available in abundance. Most of the crops and cereals are lost because of fungal and micro bacterial attacks. This wastage could be easily prevented by proper drying, which enhances storage of crops and grains over long period of time. Generally, farmers do this by open-air drying but this method is too unhygienic and time consuming. Therefore, drying crop products by solar energy play an important role in the preservation of agricultural products.

In this sense, proper utilization of solar energy for crop drying can easily be possible by choosing a proper solar dryer. Solar dryer can raise the ambient temperature to a higher value for effective drying. Several studies have been reported on drying crops and grains (Waewsak J *et al*,2006). A number of solar dryers have been constructed and designed for different crops in the literature (Forson FK *et al*,2007).

There are some individual dryers for a particular crop, and some of them are treated as multi-crop dryers (Mastekbayeva *et al*,1999). In spite of a wide range of studies of different kinds of dryers, for the selection of a particular dryer, farmers have to face some problems. Therefore, this paper presents a theoretical consideration for selecting a dryer for agriculture products.

2. Materials and methods

Different dryers available for a crop in the literature can be compared with the help of some important and essential parameters. We select the following parameters shown in Table 1 for comparing dryers with different crops. For this purpose, six major crops have been selected for the study: chilli, mushroom, groundnut, maize, pepper and yam; on the basis of the crops cultivation area in India, it is 79, 2000 hectares, 5.96 million hectares, 8.26 million hectares, 18, 4000 hectares and 11, 3000 hectares for chilli, groundnut, maize, pepper and yam respectively. Of these crops, India is largest producer, consumer, and exporter also. A brief summary of the crops, their cultivated area, and their production is given in Table 2

Table 1 Parameters for comparing dryers with different crops.

S.N.	Parameter	Reason chosen for selecting parameter
1	Maintenance and purchase cost of dryers	The main purpose of maintenance is to extend the useful life of the equipment so that productivity can be up to maximum level. Cost of the dryers will be effective for chosen the dryer either small scale farmers or large scale farmers.
2	Drying capacity	Drying capacity means that how much temp exceeds from the existing temp and maximum feasible quantity of the crops that can be used at the same time.
3	Range of crops	Dryer applicable for single crop or for other crops and grains.
4	Quality of dried product	Final moisture content after drying.
5	Adaptability to local condition	Manufacturing in local areas depending upon needs and kinds of farmers.
6	Efficiency	Solar energy/biomass energy (in case of hybrid dryers) used effectively.

*Corresponding author: C. K. Pandey, Tel.: +91 9918676947

Table 2 Crops, their cultivated area, and their production

Crop	Region	Production	Types of dryers
Chilli(Karvy special Report,2011)	Andhra Pradesh (51%), Madhya Pradesh (11%), Karnataka (9%), Rajasthan (5%), Orissa(4%), Maharashtra(4%), and West Bengal (4%) Punjab (50%),	25% of global production	1. AIT*solar tunnel dryer (AC) 2. AIT solar tunnel dryer (DC/PV) 3. Low cost solar agricultural dryer 4. New solar dryer 5. Hybrid solar dryer
Mushroom (www.thehindbusinessline.com)	Haryana and Himanchal Pradesh (40%), Uttar Pradesh, Rajasthan, Jammu Kashmir	1.5% of global Production	1.Solar tunnel dryer, 2.Solar hybrid dryer, 3.Natural convection solar dryer
Groundnut (agrimarketell.com)	Gujarat (29.63%), Tamilnadu (20.78%) Andhra Pradesh (15.23%), Karnataka (7.82 %)	18% of global production	1.Integrated solar dryer, 2.AIT solar batch dryer, 3. Mixed mode natural convection solar dryer
Maize(agrimarketell.com)	Andhra Pradesh (21%), Karnataka (16%), Rajasthan (10%), Bihar, Maharashtra (9% each), Uttar Pradesh and Madhya Pradesh (6 % each)	3% of global Production	1.Distributed passive solar dryer, 2.V – groove solar dryer, 3.Distributed type natural convection solar dryer, 4.Hybrid tunnel dryer
Pepper (agrimarketell.com)	Kerala (85%), Karnataka (10%), Tamil Nadu (3%)	25% of global production	1.Mixed mode solar dryer, 2.Integrated solar grain dryer, 3. Natural convection solar cabinet dryer, 4.Natural convection solar chimney dryer
Yam (www.en.wikipedia.org)	Not available	1.1% of global production	1.Direct passive solar dryer, 2.Mixed mode solar dryer

*AIT – Asian Institute of Technology

The efficiency η_{sys} of the solar system can be obtained using the following relation (Leon A.M *et al*,2002)

$$\eta_{sys} = \frac{W \times L}{I \times A_p}$$

where W is the weight of water evaporated from the product (kg), L is the latent heat of vaporization of water (J/kg), I is solar insolation (J/m2) and A_p is the area of solar collector (m^2).

3. Results and discussion

Chilli ripe as well as dried is a popular ingredient in Indian food, and chilli is most common spices cultivated in India. It is grown in all parts of country, hills and plain region. Experimental investigation on drying chilli has been compared with different design and shapes of solar dryers. The moisture content of raw chilli is usually in the range of 75-90%, while dried chilli contains about 4-9% of moisture. Chilli required 5-18 days for open sun drying while by solar dryers drying time varied from 12 hrs to 9 days depending on weather conditions and dryer design. The results of observations from various studies are summarized in Table 3.On the basis of the drying time, hybrid tunnel dryer and forced convection solar dryer seem to be the best but hybrid tunnel dryer requires biomass during night hours or when solar radiation is not available, since solar –biomass hybrid dryer also enables drying crop during night time and rainy season. Biomass dryer may be profitable for that area where wood or coal is abundantly available. The places where villagers have enough cattle, they can use cattle dung for generating bio fuel. Commercial users can use rind of grains, that is, wheat, maize, and so forth, as biomass fuel. But where such waste materials are not available for biomass fuel production and farmers have to buy, in that case, use of this dryer will cost high. It also requires more labor. Therefore, hybrid dryer is more useful for very large

Table 3 Comparative study of different solar dryers for chilli

Type of dryer	Moisture (%)		Drying time	Temperature (^oC)		Full load capacity	Efficiency (%)
	Initial	Final		Ambient	Average		
Low cost agricultural solar dryer (Thanvi KP *et al*,1987)	86.30%	4.10%	9 days	45	73.2	10-15 kg	7-9 %
New solar dryer(Tiris M, Dincer *et al*,1998)	89.20%	7.20%	2.5 days	42	58	20 kg	9%
AIT solar tunnel dryer (AC) (Mastekbayeva, 1998)	75.20%	6.30%	3 days	45	62.5	80 kg	9.32%
AIT solar tunnel dryer (DC/PV) (Mastekbayeva.1998)	74.90%	6.80%	2 days	45	62.5	80 kg	14.20%
Hybrid tunnel dryer (AC) (Mastekbayeva,1999)	76%	6.60%	12 hrs	20	54.5	80 kg	8.80%
Integrated forced convection solar dryer (Mohanraj M *et al*,2009)	72.80%	9.10%	24 hrs	26	31	40-80 kg	21%

Table 4 Comparative study of different solar dryers for mushroom

Type of dryer	Moisture (%)		Drying time	Temperature (^oC)		Full load capacity	Efficiency (%)
	Initial	Final		Ambient	Average		
Hybrid dryer (Mastekbayeva,1999)	92%	9.80%	12 hrs	20	70	40 kg	14.40%
Solar tunnel dryer(Bala BK *et al*,2009)	89.41%	6.14%	8 hrs	37	66.5	45 kg	38.47%

Table 5 Comparative study of different solar dryers for groundnut

Type of Dryer	Moisture (%)		Drying time	Temperature (^oC)		Full load capacity	Efficiency (%)
	Initial	Final		Ambient	Average		
Mixed mode natural convection solar dryer with biomass burner (TariganE *et al*,2005)	135%	13%	16 hrs	40	59	60-65 kg	63%
Integrated passive solar grain dryer (Ezekoye BA *et al*,2006)	80%	40.53%	8 days	31	67	~65 kg	22%
AIT solar batch dryer(www.archive.idrc.ca)	41%	9%	40 hrs	35	55	315 kg	20%

Table 6 Comparative study of different solar dryers for maize

Type of dryer	Moisture (%)		Drying time	Temperature (^oC)		Full load capacity	Efficiency (%)
	Initial	Final		Ambient	Average		
Simple solar maize dryer or Distributed passive solar dryer (Joshua Folaranmi *et al*,2008)	20-25%	13%	3 days (9 hrs each day)	20	65	50 kg	~22%
V- groove solar dryer(Mudafer Kareen *et al*,2011)	21.10%	13%	4 hrs	20	45	38 kg	45%
Distributed type natural convection solar dryer with either of the following: (Bolaji BO *et al*,2009)							
(a)Box type absorber collector	35%	12%	10 hrs	33.5	64	450 kg	60.50%
(b)Flat plate absorber collector	35%	12%	10 hrs	33.5	64	450 kg	21%
(c)Fin type absorber collector	35%	12%	10 hrs	33.5	64	450 kg	36%
Hybrid tunnel dryer (Mastekbayeva,1999)	35%	15%	4 hrs	54.5	69.4	40 kg	14.40%

production of chilli (for large-scale farmers and farm houses). For small-scale farmers, we propose low-cost agricultural dryers which can also be used for other crops also. Other solar dryers like solar tunnel dryer (AC), solar tunnel dryers (DC/PV), and new solar dryer may also be used. Mushroom is an important product agricultural pro--duct used in soups and dishes. Mushroom is edible fungi of commercial importance, and their cultivation and consumption have increased substantially due to their nutritional value, delicacy, and flavor. But mushroom is extremely perishable because of high-moisture content. Therefore, mushrooms are dried to extend their life.

Table 7 Comparative study of different solar dryers for pepper

Type of Dryer	Moisture (%)		Drying time	Temperature (^oC)		Full load capacity	Efficiency
	Initial	Final		Ambient	Average		
Mixed mode solar dryer (Akinola AO *et al*,2006)	80%	60%	5 days	31	60	60-65 kg	56%
Modified integrated solar grain dryer (Australia and New Zealand Solar Energy Society 2005. (Ezekoye *et al*,2006)	80%	56.20 %	5 days	31	67	60-65kg	22%
Natural convection Solar dryer (cabinet type) (Medugu DW *et al*,2010)	80%	35%	129 hrs (5 days 3 hrs)	39	51	50 kg	~22%
Natural convection Solar dryer (chimney type) (Medugu DW *et al*,2010)	80%	35%	105 hrs (4 days 3 hrs)	39	51	50 kg	~22%

Table 8 Comparative study of different solar dryers for yam

Type of dryer	Moisture (%)		Drying time	Temperature (^oC)		Full load capacity	Efficiency (%)
	Initial	Final		Ambient	Average		
Direct passive solar dryer(Alonge AF *et al*,2008)	62%	11.11%	26 hrs	38	59	4-5 kg	~ 40%
Mixed mode solar dryer (Bolaji BO *et al*,2008)	62%	9.06%	10 hrs	38	62	60-65kg	57.50%

Drying is one of the most importance process by which mushrooms are being preserved. Since, mushrooms are very sensitive to temperature, so special care must be taken in choosing the dryer. Various kinds of dryer are employed to dry mushroom. Every dryer has its own advantage and limitations. We selected two kinds of dryer namely solar tunnel dryer and solar-biomass hybrid dryer to dry mushroom on the basis of some essential parameters. From the results of Table 4, it is reflected that for the commercial use solar tunnel dryer are more efficient, drying in tunnel dryer takes limiting time and load capacity is also high. The areas where biomass fuel as wood, coal , rice husk briquettes , rind of grain etc are freely available they may use hybrid dryer and may increase productivity because this dryer is also applicable in nights and cloudy days .

Groundnut is considered is as one of the universally preferred oil seed crops and is grown throughout the world. Comparative study of different dryers for groundnut is listed in Table 5. Since high temp leads to cracking of grains and also leads to a change in the natural color of the product, so integrated passive solar grain dryer will be appropriate for crops and grains during low-temperature and high relative humidity periods over the year. This dryer is especially acceptable for grains. Since the dryer is sealed with glass and wood, there is no need of carrying the grains inside during nights, rain and dew in order to avoid re-wetting. But one significant limitation of solar dryers is that it can only be used during day time when there is adequate solar radiation this reason limits the production, for small scale farmers integrated passive solar grain dryer and AIT solar batch dryer are profitable but for commercial users, the ability to process continuously with reliability is important to satisfies their market. Therefore, it is necessary to provide solar dryer with any form of back up heating. The backup heating system can be constructed with easily available materials and tools and skills and it can improve viability of mixed mode natural convection solar dryer.

Maize, the “queen of cereals” provides nutrients for human and animals and serves as a basic raw material for the production of starch, oil and protein alcoholic beverages, food sweeteners and biofuel(www. agrimarketell.com). Based on our comparative study on the different kinds of solar dryers (Table 6), we observed that drying time varied 4 hrs to 3 days depending on dryer performance. Results (Table 6) indicate that simple solar maize dryer has low drying capacity, so it can be used in the places where maize production is low and not required for commercial use. Distributed-type natural convection solar dryer is more efficient, and it is available with different collector area according to the requirements. Hybrid tunnel dryer could be profitable if no need to purchase any kind of biomass fuel; that is, it is abundantly available on that area. Commercial users where hybrid dryer is not feasible economically, V-groove solar dryer which is especially preferred for drying maize can be used, it is more efficient.

Pepper is a highest moisture content product. To achieve its dried form, it takes near about 5 days. We propose four dryers (Table 7), namely, mixed-mode solar dryer, integrated solar grain dryer, solar cabinet dryer, and solar chimney dryer; these all have approximately same load capacity and drying time. We found that the mixed-mode solar dryer has highest efficiency, and it is economically viable.

Yam is used for chips. Two dryers are being proposed for drying yam chips, namely, direct passive solar dryer and mixed-mode solar dryer (Table 8). Direct passive solar dryer is an adequate low cost, simple, inexpensive and low

technology dryer. It is suitable for domestic purpose. Although mixed mode solar dryer also smaller in size and takes single unit but its efficiency is high. For effective use of solar dryers, we propose that Gram Sabha should also support or co-operate in having dryers formed; in that case costly, quick, and efficient dryers like hybrid tunnel dryers may be established.

Conclusion

From the above discussion, we can conclude that the solar tunnel dryer and solar hybrid dryer are more suitable because of higher efficiency, commercial viability, high load capacity and higher drying rate. By using solar hybrid dryer drying time can be reduce and the major advantage of both dryers is that it can be used for multi crops. Quality of dried product also found to be best.

References

Hall Carl W. (1970), Drying Farm Crops. *Lyall Book Depot.* Ludhiana: India.

Headley O,Springer BGF. (1973), A natural convection solar crop dryer. In Proceedings of the ISES/UNESCO Solar Energy Conference, *The Sun in the Service of mankind, Paris*, Paper no. V 26.

Hall C W. (1980), Drying and Storage of Agricultural Crops. *Westport*

Ikejiofor ID. (1985), Passive solar cabinet dryer for drying agricultural products. In: Awe O, Editor. African Union of Physics, Proceedings of the Workshop on the Physics and Technology of Solar Energy Conversion, *University of Ibadan*: Nigeria, p. 157-65.

Muhlbauer W. (1986),Present status of solar crop drying. *Energy in Agri*, 5: 121-37.

Imre L,Farkas I, Gemes. (1986), Construction, Simulation and Control of a Complex and Integrated Agricultural solar drying system. DRYING 86/proc. 5th Int. Drying Symposium, MIT Cambridge USA, 2: 678-684. *Hemisphere Publ. Co. Washington*.

Sodha MS,Bansal NK, Kumar A, Bansal PK, Malik MAS. (1987),Solar crop drying. Vol. 1. (Boca Raton, FL: *CRC Press*)

Brooker DB, Bakker-Arkema FW, Hall CW. (1992), Drying and Storage of grains and oilseeds. *Avi, Van nostrand Reinhold:* USA.

Ashrae handbook fundamentals. (1993),Physiological Factors in Drying and Storing form Crops. F 10.4. American society of heating, *Refrigeration, and Air Conditioning Engineers, Inc.*, Atlanta.

Imre L. (1995),Solar Drying in Handbook of Industrial Drying. ed. By Mujumdar AS, vol.1. Chapter 121, 2nd edition, *Marcel Dekker Inc*. New York.

Imre L. (1997), Solar Dryers in Industrial Drying of foods. Ed. By Baker Ch GJ, Chapter 10, Blackie academic and Professional, *Chapman and Hall*, London.

Bala, BK. (1997), Drying and Storage of cereal grains. *Oxford & IBH Publishing Co. Pvt. Ltd*. India.

Ratti C, Mujumdar AS. (1997), Solar drying of foods: modeling and numerical simulation. Sol energy ,60:151-157.

Alonge, AF. (1997), A Natural Convection Solar crop dryer. Proceedings of 19th annual Conference of the *Nigerian Society of Agricultural Engineers (NSAE)*,19: 211-214.

Hollick JC. (1998),Commercial scale solar drying. Renewable Energy,16: 714-719.

Headley, Oliver St C. and Hinds, Willium , Medium scale solar crop dryers for agricultural Products, centre for Resource Management and Environmental studies, *University of the West Indies, Cave Hill Campus*.

Adegoke CO, Akintaro AO. (2000),Performance Evaluation of a Natural Convection solar Grain dryer under a tropical Humid Climate. *J. Sci, Engin. Tech*,7:4.

Itodo IN, Obetta SE, Satimehin AA. (2002), Evaluation of a solar crop dryer for rural applications in Nigeria. *Botswana J. Technol*, 11(2): 58-62.

Bolaji BO. (2003),The Role of Solar Energy in Preservation of Agricultural Products in Nigeria. In: Challenges of Environmental Sustainability in a Democratic Government. *Eds.Adekunle V,Okoko E, Adeduntan S.Proceedings of 11th annual conference of Environment and Behavior Association of Nigeria (EBAN)*, pp: 187-193.

Waewsak J, Chindaruksa S, Punlek C. A (2006), mathematical modeling study of hot air drying for some agricultural products. *Thammasat Int J Sci Technol*., 11(1): 14-20.

Forson FK, Nazha MAA, Rajakaruna H. (2007), Modeling and experimental studies on a mixed –mode natural convection solar crop-dryer. Sol energy, 346-357.

Thanvi KP, Pande PC. (1987), Development of a low cost solar agricultural dryer for arid regions of India. *Energy in Agri.* 6:35-40

Tiris M, Dincer I. (1998), Experimental testing of a new solar dryer. *Int. J Energy research*, 18: 483-490.

Mastekbayeva, Gauhar A, Leon Augustus M, Kumar S. (1998), Performance evaluation of a solar tunnel dryer for chilli drying. *ASEAN Seminar and Workshop on Drying Technology, Phitsanulok*, Thailand.

Mastekbayeva, Gauhar A. (1998), Performance Enhancement of AIT solar tunnel Dryer, Master Thesis, ET-98-1, *Asian Institute of technology, Bangkok*: Thailand.

Mastekbayeva, Gauhar A, Bhatta P (1999), Chandika, Leon Augustus M, Kumar S. Experimental studies on a hybrid dryer. *ISES 99 solar world congress, Israel*,

Hossain MA. (2003), Forced convection solar drying for chilli. PhD thesis. *Bangladesh Agricultural University. Mymensingh.*

Hossain MA, Bala BK. (2007), Drying of Hot Chilli using Solar Tunnel Dryer. *Sol Energy*, 81:85-92

Mohanraj M, Chandrasekar P. (2009), Performance of a forced convection solar drier integrated with gravel as heat storage material for Chilli drying. *J Engin Sci and Tech* ,4(3):305-314.

Middili A, Olgun H, Ayhan T. (2001), Experimental studies on mushroom and pollen drying. *Int J Energy Res*, 23(13): 20011143-1152.

Bala BK, Morshed MA, Rahman MF. (2009), *Solar drying of mushroom using solar tunnel dryer. Bangladesh Agricultural University, Mymensingh*.

TariganE, Tekasakul P. (2005),A mixed mode Natural Convection Solar Dryer with Biomass Burner and heat storage back up heater. *Australia and New Zealand Solar Energy Society*.

Ezekoye BA, Enebe OP. (2006), Development and performance Evaluation of Modified Integrated Passive Solar grain dryer; *J Sci and Tech*, Vol 7.

http://archive.idrc.ca/library/document/046680/chap5_e.html. Evaluation of existing drying equipment in Northern Thailand.

Joshua Folaranmi. (2008), Design construction and testing of simple solar maize dryer, *Leonardo electronic Journal of Practices and Technologies*, ISSN 1583-1078; p.122-130.

Mudafer kareen Abduiiah, Ahmed Abed Gatea. (2011), Performance evaluation of a V-groove solar air collector for

drying maize (zea Mays) in Iraq; *African J agri Res*, 6 (4):817-824.

Bolaji BO. (2005), Development and Performance Evaluation of a Box– type Absorber solar Air Collector for crop drying. Grace Publications. *J Food Technology*, 3(4):595-600

Simate IN. (2001), Simulation of mixed–mode Natural Convection solar Drying of Maize. *Drying Technology*,19(6):1137-1155.

Akinola AO, Fapetu OP (2006), Exergetic Analysis of a Mixed–Mode Solar Dryer, *J Engin. and App. Sci*, 1(3): 205-210.

Janjaia S, Srisittipokakuna N, Balab BK. (2008), Experimental and Modelling performances of a roof- integrated solar drying system for herbs and spices. *J Energy*, 33: 91-103.

Medugu DW. (2010), Performance study of two designs of solar dryers. Scholars Research Library, *Archives of App Sci Res* 2010; 2(2):136-148.

Alonge AF, Hammed RO.A direct Passive solar dryer for tropical crops. *African Crop Science Conference Proceedings* 8,1643-1646.

Bolaji BO, Olalusi AP. (2008), Performance Evaluation of a Mixed – mode solar dryer. *AUJT* ,11(4): 225-231.

Azad E. (2008), Design and Experimental study of solar Agricultural dryer for rural area. *Iranian Research Organization for Science & technology (IROST)*, Tehran: Iran.

Oguntola J, Alamu, Collins N Nwaokocha, Olayinka Adunola . (2010), Design and Contruction of a Domestic Passive solar Food Dryer. *Leonardo Journal of Sciences*, ISSN 1583-0233, p. 71-82.

Chy Cheapok, Pen Pornnareay; (a) solar Cabinet dryer (b) solar Chimney dryer; Introducing solar drying in a developing Country: The case of Cambodia; Phnom Penh,Combodia.

Karvy special Report. Spices board of India & KCTL Research; 2011

http://www.thehindbusinessline.com/industry-and-economy/agri-biz/article021529.ece.

http://agrimarketell.com/node14

http://en.wikipedia.org/wiki/sweet_potato.

Leon A.M., Kumar S., Bhattacharya S.C. (2002), A comprehensive procedure for performance evaluation of solar food dryers, *Renewable and Sustainable Energy Reviews*, 6, 367–393.