Performance Evaluation of Hybrid Solar Dryer with Flat Plate Collector for Drying Coleus Forskohlii Roots and Stems

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Abstract
Solar Energy is having special attention towards researchers in India since it is located at Latitude of 22° north and Longitude 77° west and also having the availability of sunlight for minimum of 9 to 10 months in a year. Coleus forskohlii is a botanical that has been used since ancient times in Hindu and Ayurvedic traditional medicine. The Root and Stem portion of the plant has been traditionally used for medicinal purpose and it contains the active constituents and forskolin. In this work, performance evaluation of Hybrid model solar dryer that is integration of solar dryer with the ancillary source of biomass heater is carried out for drying Coleus forskohlii roots and stems. Solar dryer designed with Flat plate collector. The Hybrid dryer was able to reduce the moisture content of the roots and stems to the recommended level respectively 8% and 11.8% in about 12 hours and 6.8% and 8.7% in about 16 hours. The reliability of the system is evaluated using uncertainty analysis. At the same time open sunlight method is produced the moisture content for coleus roots is 28% in about 48 hours and 17% in about 35 hours. Hybrid model produced better products than the open sunlight products.
Keywords: *Hybrid model; Solar Energy; Coleus forskohlii roots: stems; Open sun light.*

1. Coleus Forskohlii

Coleus forskohlii is part of the mint family of plants and has long been cultivated in India, Thailand and parts of South East Asia as a spice and as a condiment for heart ailments and stomach cramps. The Stems of the plant are a natural source of forskolin, the only plant-derived compound presently known to directly stimulate the enzyme adenylate cyclase, and subsequently cyclic. This species is a perennial herb with fleshy, fibrous Stems that grows wild in the warm subtropical temperate areas in India, Burma and Thailand. It is one of the 150 coleus species, which are commonly cultivated as ornamental plants, because of their colorful foliage. The Stems of C. forskohlii, unlike other coleus species, are used for health purposes. Coleus forskohlii belonging to the family Labiatae was collected in 1973 from Dehra Dun in North India for targeted pharmacological screening for its phylogenetic relationship to a medicinal herb, C. amboinicus. Diterpene Forskolin was derived as active alkaloid from the Stems.

Fig.1. Coleus forskohlii Stems

Fig.2. Dry Coleus Roots

Figure 1 shows the Coleus Forskohlii Stems and Figure 2 Shows the dry Coleus Roots which we have taken for our work. In this work Hybrid model of Solar-Biomass system has been used to dry the Coleus Stems. It leads better performance than other methods.

1.1. Uses and Benefits of Coleus

- Coleus is found to be effective in skin conditions as eczema and psoriasis.
- Coleus is primarily indicated for cardiovascular diseases including hypertension, congestive heart failure and angina.
- Studies have indicated the use of coleus for asthma, intestinal colic, uterine cramps, as well as painful urination.
- Coleus can aid in weight loss due to its ability to breakdown stored fat as well as inhibit the synthesis of adipose tissue, additionally, it increases thyroid hormone production and release thereby increasing metabolism.
- Ophthalmic preparation of forskolin to the eyes lowers eye pressure thus reducing the risk of Glaucoma.

Coleus can aid in digestive and malabsorption disorders through its ability to stimulate secretion of saliva, hydrochloric acid, pepsin, amalyase and pancreatic enzymes and increase nutrient absorption in the small intestine.

1.2 Solar Dryer

Dehydration, or drying, is a simple, low- cost way to preserve food that might otherwise spoil. Drying remove water and thus prevents fermentation or the growth of molds. It also slows the chemical changes that take place naturally in foods, as when fruit ripens. Surplus grain, vegetables, and fruit preserved by drying can be stored for future use [13, 14]. People have been drying food for thousands of years by placing the food on mats in the sun. This simple method, however, allows the food to be contaminated by dust, air borne molds and fungi, insects, rodents, and other animals. Furthermore, open air drying is often not possible in humid climates. Although solar dryers involve an initial expense, they produce better looking, better tasting, and more nutritious foods, enhancing both their food value and their marketability [15]. They also are faster, safer, and more efficient than traditional sun drying techniques. An enclosed cabinet-style solar dryer can produce high quality, dried foodstuffs in humid climates as well as arid climates. It can also reduce the problem of contamination. Fruits maintain a higher vitamin C content. Because many solar dryers have no additional fuel cost, this method of preserving food also conserves non-renewable sources of energy [16, 17]. This paper describes some of these dryers and discusses the factors that must be considered in determining what kind of dryer is best suited for a particular application. Drying products makes them more stable and in the case of foods, allow them to be stored safely for long periods of time. Safe storage requires protection from the growth of molds and other fungi, the most difficult of the spoilage mechanisms to detect and control [18]. Solar dryers have the principal advantage of using solar energy – a free, available, and limitless energy source that is also nonpolluting [19, 20]. Drying most foods in sunny areas should not be a problem. Most vegetables, for example, can be dried in 2-1/2 to 4 hours, at temperatures ranging from 43 to 63 [degrees] centigrade (110 to 145 [degrees] Fahrenheit). A solar food dryer improves upon the traditional open – air systems in five important ways:

1. It is faster; food can be dried in a shorter amount of time.
2. It is more efficient .Since food stuffs can be dried more quickly; less will be lost to spoilage immediately after harvest. This is especially true of produce that moisture content. In this way, a larger percentage of food will be available for human consumption.
3. It is safer .Since foodstuffs are dried in a controlled environment, they are, less likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi.
4. It is healthier. Drying foods at optimum temperatures and in a shorter amount of time enables them to retain more of their nutritional value – especially vitamin C.
5. It is cheaper. Using solar energy instead of conventional flues to dry products.

Conventional type plain tube evacuated collectors was manufactured for the use of sunny and also for warm weather climates [21]. Various characteristics of a typical Evacuated Plain Tube Collector (EPTC) are shown in below table1.

Table.1 Characteristics of Evacuated Plain Tube Collector (EPTC)

S.No	Parameter	Value
1.	Glass tube diameter	72 mm
2.	Glass thickness	1.7 mm
3.	Collector length	2150 mm
4.	Absorber plate	Copper
5.	Coating	Selective

2. Literature Review

Dehydration is a common technique for preservation of agricultural and other products, including fruits and vegetables. In developing countries, the traditional method of dehydration is by open air, which often results in food contamination and nutritional deterioration [1]. Some of the problems associated with open-air drying can be solved through the use of solar dryers which are generally classified, depending on the mode of heating or operation, into: (a) direct, (b) indirect and (c) mixed mode systems with natural or forced circulation of the drying air. In the direct dryer, solar radiation passes through a transparent cover fitted on the top part of the dryer and is directly absorbed by the crop placed on the drying bed under the transparent cover. In an indirect dryer, air is heated in a separate solar collector and circulated through the drying bed where it picks moisture from the crop. The mixed mode possesses both features of the direct and indirect categories of solar dryers. In particular, dryers of the natural-convection variety are popular because they are cheap and simple to operate and maintain [2,3].

They exhibit enormous potential for exploitation in remote areas of developing countries, where most of the rural communities have no access to electricity. Nevertheless, one disadvantage of solar drying is that the dehydration process is interrupted at night or under low insulation, resulting in a poor quality of the dried product was capable of transferring 118 W m_2 to the drying air. They have designed and constructed a solar dryer with a rock storage system. It was found that the rock pile stored enough energy to enhance nocturnal drying. The duration of crop drying in the solar dryer was shorter than that in the open air [4,5,6]. And also developed a solar air heater and tested it with and without thermal storage for drying agricultural products. They found that the drying process would continue at night when a thermal mass was used. They have developed a solar dryer with a thermal storage system. The dryer was tested with and without thermal storage. They found that the storage material reduced the drying period [7,8].

They used a phase change material to store thermal energy in a solar air heating system. It was found that the system could be operated for crop drying and poultry egg incubation. In all these studies, solar energy was used exclusively. However, the intensity of solar radiation is sometimes so low that the temperature of the thermal mass may rise by an insignificant margin above the ambient level, and thereby limiting the continuity of dehydration. There is, therefore, still need to backup the drying process in solar dryers with thermal mass. The dryer was tested in three operational modes (solar, biomass and solar–biomass) by drying fresh pineapple [10, 11]. Outdoors under different weather conditions. Results show that the dryer is capable of reducing the moisture content of pineapple slices to acceptable levels, and retaining part of the vitamin C in the slices [12]. The drying process is fastest in the solar–biomass mode of operation while the efficiency of the system is most satisfactory in the solar mode. So consider these literatures in this work we have proposed the Solar-Biomass integrated Hybrid system to dry the Coleus Forskohlii Stems.

3. Design of Proposed System

Three – dimensional solar cells that capture nearly all of the light that strikes them and could boost the efficiency of photovoltaic systems while reducing their size, weight and mechanical complexity. The new 3D solar cells capture photons from sunlight using an array of miniature “tower” structures that resemble high-rise buildings in a city street grid. Figure.3 shows Prototype model of solar system. Then Figure.4 shows the proposed work sequence and Figure.5 shows Plain tube collector, Figure.6 indicating the Bio-mass setup of our experimental work and Figure.7 shows the setup model of our proposed Hybrid model of Solar – Biomass system.

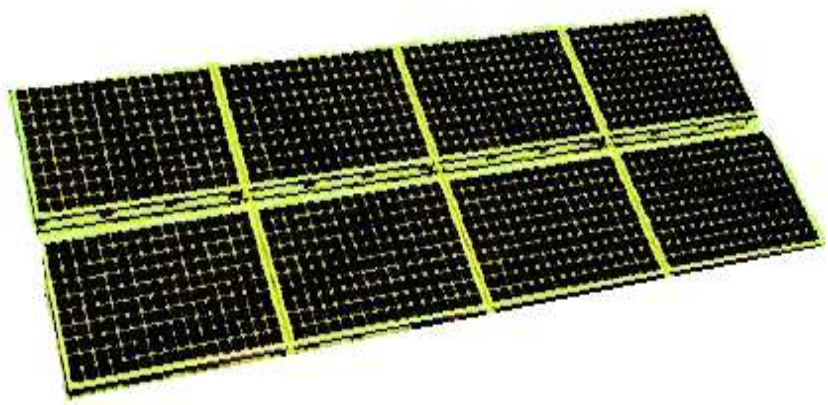

Fig.3. Prototype Solar Model Design

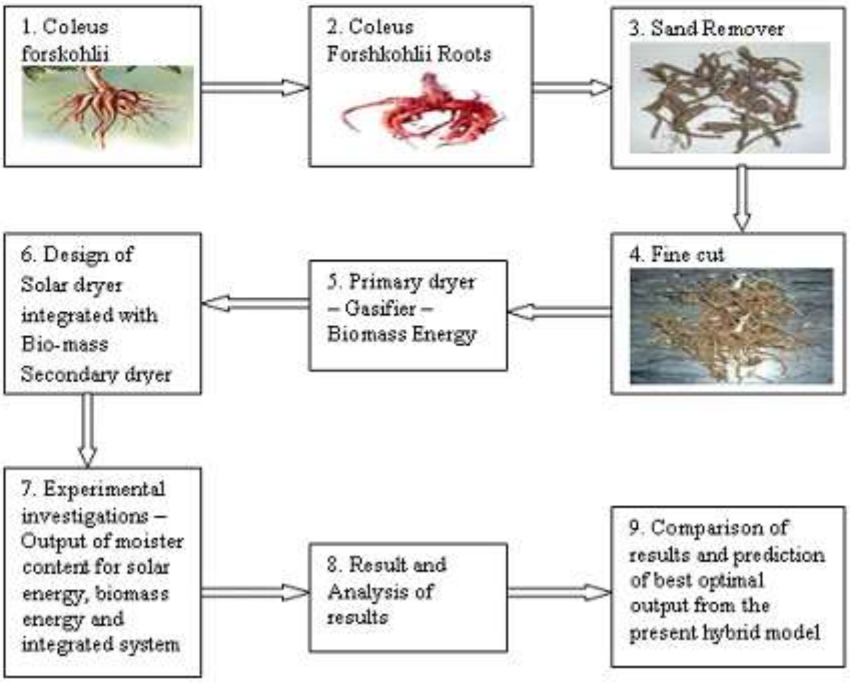

Fig.4. Work sequence of proposed Hybrid system

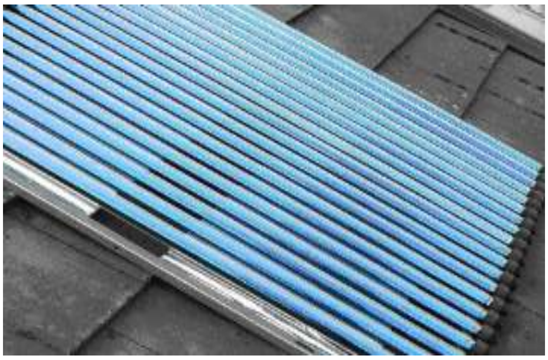

Fig.5. Plain Tube collector

Fig.6. Model Design of Biomass system

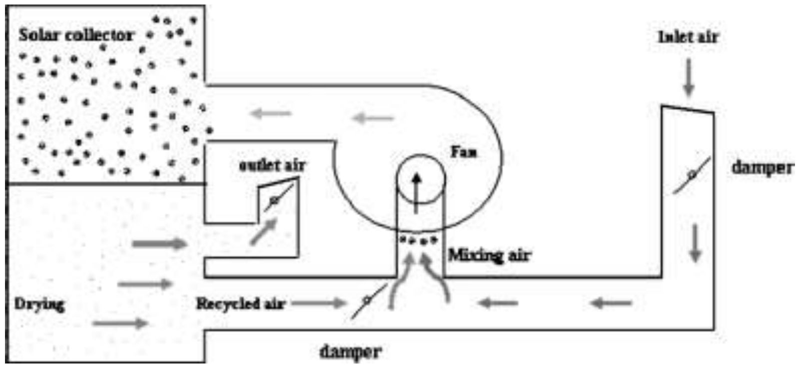

Fig.7. Model Design of Hybrid Solar -Biomass system

4. Results and Discussion

In this work, we have adopted the plain tube collector solar dryer with natural circulation mode. The experimental Nusselt number and friction factor are compared with the fundamental equation and the deviations are also found to be fall within the acceptable limits. The theoretical Nusselt Number for this system is estimated using Sieder-Tate equation.

$$N_u = 1.86\ (G_z)^{1/3}\ (\mu/\mu_w)^{0.14} \text{ for } G_z > 10 \qquad [1]$$

The experimental Nusselt number is substituted with the above equation for the experimental work. The maximum deviation is found to be within the acceptable limit of ± 7.95%.

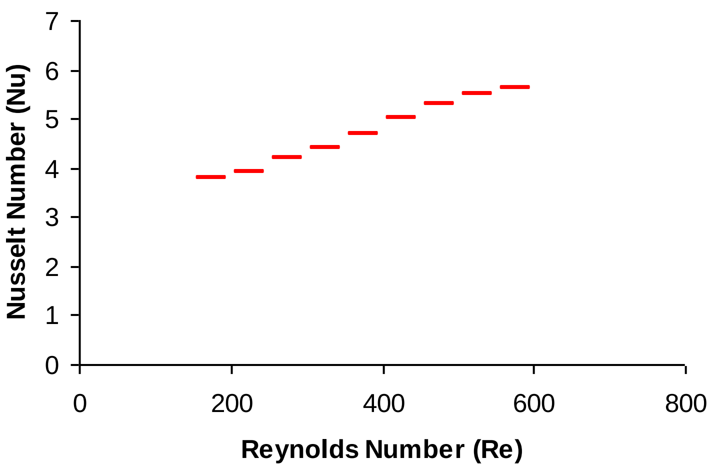

Fig. 8. Nusselt number experimental data analysis

The thermal performance of friction factor of a solar dryer is calculated using the Hottel and Whillier equation as follows:

$$\eta = F_R(\tau\alpha) - F_R U_l\ (T_{in} - T_\alpha)\ /\ H_t \text{ for } F_R > 15 \qquad [2]$$

The experimental friction Factor is substituted with the above equation for the experimental work. The maximum deviation is found to be within the acceptable limit of ± 13.65%.

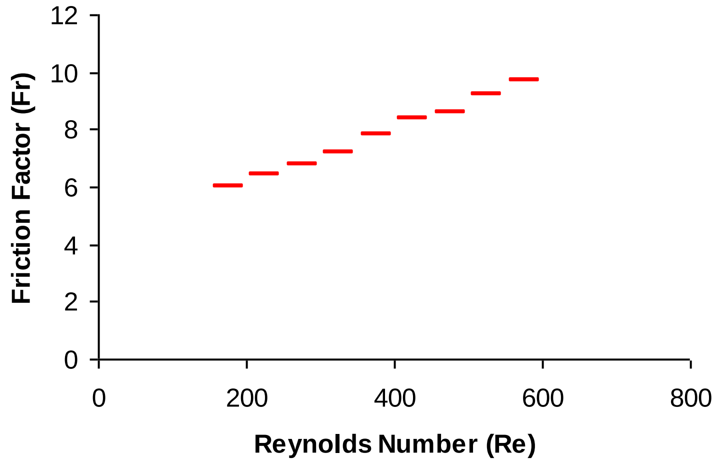

Fig. 9. Friction Factor experimental data analysis

In this work we have proposed the Hybrid model of Solar – Biomass setup to dry the Coleus forskohlii Stems and Roots. First we have tried with only solar model then the moisture content of the Coleus Stems will be 31%. Because only solar system will produced lower percentage of performance while it reduced the moisture content from 89% to 31%. Later we have tried with our experiment setup of Bio-mass system it produced nominal percentage of moisture content that is 16.7%. Finally we have proposed the Hybrid setup of Solar-Biomass system to dry the Coleus Stems. It produced the better percentage of moisture content that is our proposed hybrid model reduced the moisture content from 89% to 11.8% in 12 Hours and 8.7% in 16 Hours. Table 2 shows the output results of all the methods for stems. Figure 9 shows that the graphical analysis of output. Like initial moisture content of the Coleus Roots will be 83%. First we apply the Solar system. This system produced 28% moisture content and Biomass system produced roots contains 14.2% moisture content. But finally we have applied the hybrid model for roots, it gives 8% moisture content with 12 hours duration and 6.8% moisture content with 16 Hours duration. Product quality is also good compare than other methods, because all the heat methodology applied as continuous exposure. Table 3 shows the output results of all the methods for roots, as figure 12 and 13 shows the graphical analysis.

Table.2. Comparative results of Moisture content of Coleus forskohlii Stems

S.No	Solar Dryer model (Moisture content %)	Bio-mass dryer (Moisture content %)	Hybrid model (Solar dryer + Bio-mass Dryer) (Moisture content %)
1	31%	16.7%	11.8%

Table.3. Comparative results of Moisture content of Coleus forskohlii Roots

S.No	Solar Dryer model (Moisture content %)	Bio-mass dryer (Moisture content %)	Hybrid model (Solar dryer + Bio-mass Dryer) (Moisture content %)
1	28%	14.2%	8%

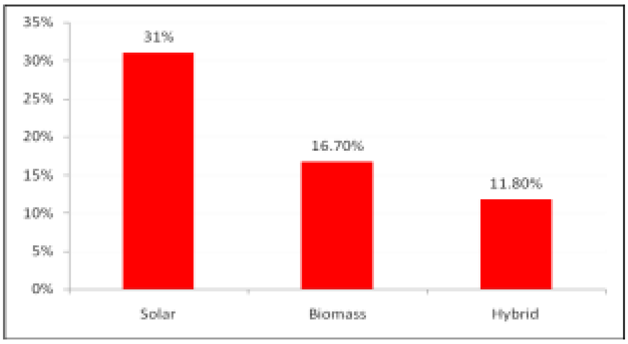

Fig.10. Comparison of output (Stems)

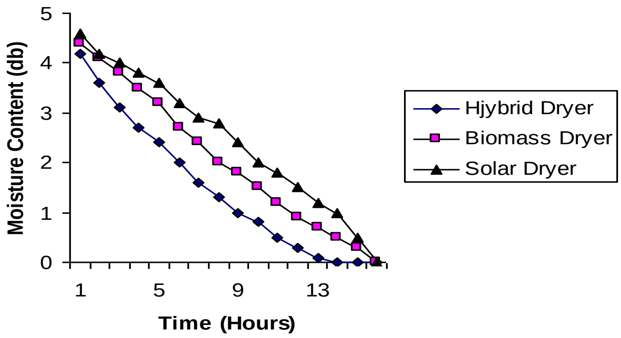

Fig. 11. Comparison of Time Vs Moisture content of various categories

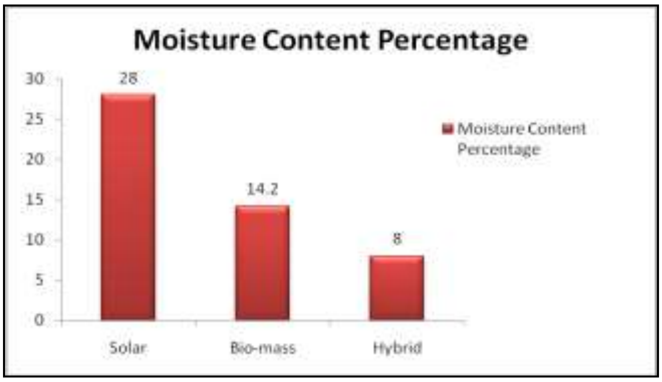

Fig.12. Comparison of output (Roots)

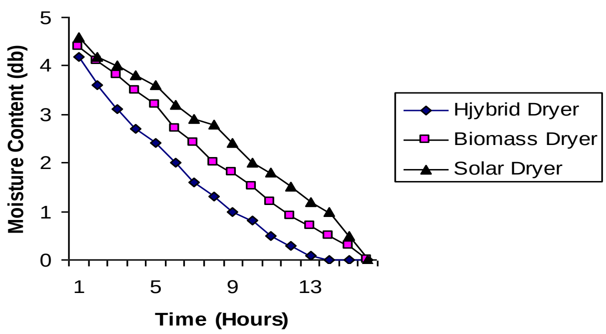

Fig. 13. Comparison of Time Vs Moisture content of various categories

5. Conclusion

In this work an integrated Hybrid type of Solar dryer has been designed integrated with Biomass Energy and evaluated using experimental study of drying Coleus Stems. Experimental investigations of heat transfer, friction factor and thermal performance of hybrid model of plain tube collector type of solar dryer integrated with Bio-mass backup heater are analyzed. Experiments are carried out for plain tube method under natural circulation mode. Then the experimental Nusselt number and friction factors are compared and the predictions are made the deviations are found to fall within the acceptable limits of ± 7.95% and ± 13.65%. And also integrated system is to be evaluated using three methods like only solar dryer, only biomass dryer and Hybrid technique of solar dryer integrated with bio-mass dryer. Moisture content of the Coleus Stems has been determined using three ways. A result shows that the Integrated Hybrid model produced the best optimum results. Hybrid model produced the moister content of the Stems has been 11.8%, whereas Solar dryer produced 31% and Bio-mass produced 16.7%. Integrated model produced the better optimum results. And also Hybrid model produced the moister content of the Roots has been 8%, whereas Solar dryer produced 28% and Bio-mass produced 14.2%.

References

1. *A. Farhat, S. Kooli, C. Kerkeni, M. Maalej, A. Fadhel, A. Belghith, Validation of a pepper drying model in a polyethylene tunnel greenhouse, International Journal of Thermal Sciences 43 (1) (2004) 53–58.*
2. *Ayensu, A., 1997. Dehydration of food crops using a solar dryer with convective heat flow. Solar Energy 59 (4–6), 121–126.*
3. *Bala, B., Mondol, M., Biswas, B., Chowdury, B., Janjal, S., 2003. Solar drying of pineapple using solar tunnel drier. Renewable Energy 28, 183–190.*
4. *Bena, B., Fuller, R., 2002. Natural convection solar dryer with biomass back-up heater. Solar Energy 72 (1), 75–83.*
5. *B.M.A.Amer, M.A.Hossain and K.Gottschalk., 2010, Design and performance evaluation of a new hybrid solar dryer for banana., Energy Conversion and management, 51 (2010), 813-820.*
6. *Chang JM, Leu JS, Shen MC, Huang BJ. A proposed modified efficiency for thermosyphon solar heating systems. Solar Energy 2004; 76:693–701.*
7. *Chen, H., Hernandez, C.E., Huang, T., 2005. A Study of the drying effect on lemon slices using a closed-type solar dryer. Solar Energy 78 (1), 97–103.*
8. *Chow TT, He W, Ji J, Chan ALS. Performance evaluation of photovoltaic– thermosyphon system for subtropical climate application. Solar Energy 2007; 81:123–30.*
9. *Crawford RH, Treloar GJ. Net energy analysis of solar and conventional domestic hot water systems in Melbourne, Australia. Solar Energy 2004; 76: 159–63.*
10. *El-Beltagy A, Gamea GR, Amer Essa AH. Solar drying characteristics of strawberry. Journal of Food Engineering 2007; 78(2):456–64.*
11. *Esen M, Esen H. Experimental investigation of a two-phase closed thermosyphon solar water heater. Solar Energy 2005; 79:459–68.*
12. *Hassan MK, Shipton WA, Coventry R, Gardiner C. Extension of banana shelf life. Aust Plant Pathol 2005; 33(2):305–8.*
13. *Huang BJ, Lee JP, Chyng JP. Heat-pipe enhanced solar-assisted heat pump water heater. Solar Energy 2005; 78:375–81.*
14. *I.N. Simate, Optimization of mixed mode and indirect mode natural convection solar dryers, Renewable Energy 28 (3) (2003) 435–453.*
15. *Mathlouthi, M., 2001. Water content, water activity, water structure and the stability of foodstuffs. Food Control 12, 409–417.*
16. *McMinnWAM. Thin-layer modelling of the convective, microwave, microwave convective and microwave-vacuum drying of lactose powder. Journal of Food Engineering 2006; 72:113–23.*

17. *Midilli A, Kucuk H. Mathematical modeling of thin layer drying of pistachio by using solar energy. Energy Conversion and Management 2003; 44(7):1111–22.*
18. *N. Rahman, S. Kumar, Transient temperature analysis of potato during drying: theoretical modeling and experimental validation, International Journal of Ambient Energy 27 (4) (2006) 171–180.*
19. *OthmanMYH, Sopian K, Yatim B, Daud WRW. Development of advanced solar assisted drying systems. Renewable Energy 2006; 31:703–9.*
20. *Prasad, J., Vijay, V.K., 2005. Experimental studies on drying of Zingiber officinale, Curcuma l. and Tinosopora cordifolia in solar–biomass hybrid drier. Renewable Energy 30, 2097–2109.*
21. *Thu r A, Furbo S, Shah LJ. Energy savings for solar heating systems. Solar Energy 2006; 80:1463–74.*