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Advancement in design and performance of different solar dryers: A review

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Abstract. Uncertainty in the price of the fossil fuels and also rapid depletion of them gives rise to the alternate energy sources. From many decades people uses the solar energy as a main source of energy especially in the drying of food items. Solar dryer is the device that can be used for drying of food items which is sustainable by small communities, gives hygenic and quality products. Mainly an indirect solar dryer and mixed mode solar dryer performance and design were studied from the literatures. The tunnel type dryer has the advantages of the direct sun light by ultra-violate stabilized cover and absorber plate is provided at the base. The no load performance index is the new terminology for checking the performance of the different dryer in the forced and natural convection mode. The drying of fish near to the coastal line of India is the major business for fisherman hence the drying done by open sun drying method in very unhygienic condition. By implementing solar dryer over that regions quality of dried fish will increase and the drying time will be decrease. The no load performance index (NLPI) of the mixed mode solar dryer was 0.633 which was highest among the rest of the dryer under the natural convection mode. The new mixed mode type solar dryer can be developed in which the absorber plate is attached with the tunnel type dryer.

Keywords: Indirect solar dryer, Mixed mode solar dryer, No load performance Index. Tunnel type dryer

I. Introduction

In India during the whole year solar radiation is high, mostly in the western part solar radiation is high and relative humidity is low hence sun is the major source of energy. In the present scenario, the demand for the energy is increasing whereas the source and supply of the fossil fuel is depleted hence it is mandatory to developed the alternate source for fossil fuels for the developing countries like India. Renewable energy is the developing area for the alternate energy sources. As well as climate change is the major factor which is considered worldwide for use of renewable resources.

In India post harvesting losses are more due to the improper treatment of food items after the harvesting. After harvesting to preserve the food items for the long duration of time they are drying by the open sun drying method. India has a very large coastal line starting from the Bay of Bengal to veraval in Gujarat through which Fishing is a major industry in its coastal states, employing over 14 million people. The food items under the drying may also tend to reabsorption of the moisture under the cloudy condition and during the night which reduces the quality of the dried product (Chavda and Kumar, 2009) [1]. As shown in Figure 1The open sun drying method has the main disadvantages such as time consuming drying process, drying process may not be uniform, requirement of large drying area, contamination of food items by excreta, dust, insects, birds and cloudy and rainy weather condition can affect the drying process.

Figure 1: Open sun drying

Many researchers had developed the solar dryers of different type but still there is scope for improving the efficiency for the existing available solar drying systems. Technically drying is the process of removing access water from the product to the standard required level for preservation of it for the long duration (V.Belessiotis and E. Delyannis, 2010)[2]. Solar dryer is the simple and easily adoptable technology by small and household communities, yet it is not commercialized as much. M.Kumar et al Gives the classification of the solar dryers in mainly direct solar dryer, indirect solar dryer and mixed mode solar dryer which may be passive or active [3]. A.Mustayen et al reviewed the performance of different solar dryers the objective of the study is to identify related technologies that can help in improving existing solar dryers. For indirect solar dryer reverse flat plate collector was used and gave best results, high quality drying products are get by producing higher efficiency, is available for small farms. Mixed mode solar dryer contains separate collectors and this dryer is used for drying crops in wet season, the drying rate was highest and is used for drying rubber, rough rice [4]. Drying temperatures and moisture contents are the most important variables for controlling the drying rate. Comparing the three kinds of dryer, the mixed mode solar dryer is the best of the three because it has the highest drying rate.

II. Indirect solar dryer

S.Maiti et al designed and developed an indirect solar dryer for drying of papad (a popular Indian wafer). Author suggested the proper design for the entire indirect solar dryer and collector area of the indirect solar dryer is estimated as the function of the quantity of the products to be dried. The proposed complete design for the indirect solar dryer is as follows. The main parameters which are considered for the design are collector area, drying chamber area, and moisture to be removed from the product [5].

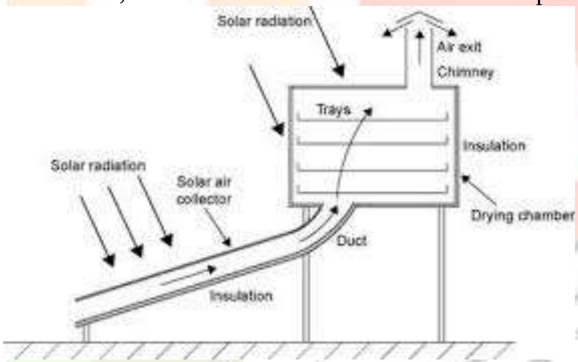

Figure 2: Indirect solar dryer

Amount of the moisture to be removed from the product is given by:

$$M_w = \frac{M_L(X_i - X_f)}{(100 - X_f)} \quad (1)$$

The quantity of heat required to evaporate the moisture is given by:

$$Q = \frac{M_w h_{fg} \eta_{dr}}{\eta_{co}} \quad (2)$$

The collector area is calculated from the given formula:

$$A_c = \frac{10^{-3} Q}{t_d \, I_{ci} \, \eta_{co}} \quad (3)$$

Area of vent is calculated from the following expression:

$$A_{vent} = \frac{M_a}{(3600 \, \rho_o \, w_s)} \quad (4)$$

The width of the air vent is given by:

$$W_v = A_v / L_v \quad (5)$$

Where in X_i, X_f, h_{fg}, I_{ci}, W_s, ρ_o are the initial moisture content, final moisture content, latent heat of vapourization, insolation, wind speed and density of air respectively. The absorber material is made by wire mesh so as the air can collect more heat from the absorber plate. The innovative design was provided by attaching the north- south reflector in the V-trough alignment to the collector plate as a result the collector and the drying efficiency was increased.Moisture transfer in food products are given by mathematical models proposed by Fick's law of diffusion. The drying equation for find out the diffusivity of the food product is determined by the equation (6). The effective diffusivity for the food product was determined and is well matched with the standard diffusivity obtained by the researches

$$\frac{\partial X}{\partial t} = D_{eff}\,\frac{\partial^2 X}{\partial y^2} \tag{6}$$

A.Lingayat et al designed and developed the indirect solar dryer for drying of banana. An experiment was conducted to study drying characteristics of banana. V-corrugated absorber plate is provided to maximize the heat gain from collector to draft of air. The moisture ratio is calculated by given equation (7-8). The M_t, M_e, M_i, and t are moisture content at time t, equilibrium moisture content, initial moisture content respectively [6].

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} \tag{7}$$

The drying model is given by the equation:

$$MR = 1 + Mt + Nt^2 \tag{8}$$

V.N.Hegde et al developed the natural convection indirect solar dryer for obtaining drying characteristics of banana. The top flow and bottom flow is provided in the absorber plate and it is concluded that heat loss is less in the bottom flow as compared to the top flow. The wooden skewers in the drying chamber are found to be more effective than the conventional rack and moisture removed from the product kept on the wooden skewers is at the high rate [7]. A new natural convection indirect solar dryer is developed for drying of food items in which the connection between the collector and the drying chamber is made by the flexible material to continuously change the tilt of the collector according to the sun's position [8]. (D.R.Pangavhane et al, 2000). The mathematical model used for calculating the mass flow rate is given by the author.

D.Jain et al developed the new indirect natural convection solar dryer which is provided with the phase change material as a paraffin wax which is capable to absorb the latent heat during the high solar radiation and reject the heat after the sun shine hours in the form of the latent heat. The solar dryer is effectively operated after the sunshine for the 5-6 h. The temperature inside the drying chamber can be maintained 5-6ºC higher than the atmospheric air after the sunshine hours. The thermal performance of the dryer is given by the equation. The payback period for the dryer is very less by using the PCM [9].

D.Acharya et al developed the rack type indirect solar dryer and concluded that the indirect solar dryer is more efficient than the direct solar dryer and by providing the racks the dryer capacity can be increased [10]. J.Banout et al developed an indirect double pass solar dryer for drying of red chillies. The dryer is provided with the transparent polycarbonate roof which is UV stabilized with absorber as the base area of it. The qualities in terms of colour, vitamin content is highest among the comparison between the cabinet dryer and open sun drying with shortest drying time [11]. A.G.F.Pastrana developed the indirect solar dryer for drying of the NOPAL. The collector portion of the indirect solar dryer is provided with the baffles to improve the heat capacity of the air which further leads to drying chamber. The loss of mass of the function as a function of time and decreases exponentially [12].

A.Sreekumar et al developed the indirect cabinet dryer for drying of bitter gourd, the food products were kept below the absorber plate to prevent from the direct sunlight for discoloration and texture change. The payback period of the dryer was found to be very less as compared to its life and also it was economically viable for drying of vegetables and fruits [13]. V.K.Sharma et al designed and developed the new indirect natural convection solar dryer for drying and preservation of food items in rural sectors [14]. A.A.El.Sebaii and S.M.Shalaby perform the experimental investigation by developing the indirect natural convection solar dryer for drying of thymus and mint. The indirect mode forced convection solar dryer was provided with V-corrugated absorber plate. The thymus and mint reached to the desired moisture content after the 34h and 5h.14 drying mathematical models were applied to the moisture ratio obtained experimentally and best model was found out which fits to the drying curves.Midilli and Kucuk model was fits to the drying data obtained experimentally. The thin layer drying models are useful for the prediction of the drying behaviour of the crops. Some of the drying mathematical models for the moisture ratios are given by the author. Whereas MR is the moisture ratio, a, b, k and n are the model constants and t is the drying time [15].

Table: 1 Mathematical model for moisture ratio.

Lewis model	MR =exp(-kt)
Page model	MR = exp(-kt^n)
Midilli and Kucuk Model	MR = aexp(-kt^n) +bt

S.Singh and S.Kumar gives the testing method to predict the performance analysis of the different solar dryers. The no load performance index (NLPI) which is dimensionless parameters was determined based on laboratory test data of the solar dryers. NLPI of the solar dryer may vary from 0 to higher number and it is desirable to have high NLPI for the great performance of the dryer under the full load condition. The NLPI of the mixed mode solar dryer was found to be highest (0.633) among rest of the types in natural convection mode. In forced convection mode it is greater than 1 and depends upon the mass flow rate inside the dryer. The proposed study was helpful to standardize the solar dryer. Also the uncertainty analysis was done for the no load performance index. The mass flow rate affects the NLPI while drive the dryer in the forced convection mode. In the forced convection mode it was found that the NLPI of the mixed mode solar dryer was highest (1.602) at air velocity of the 0.026m/s [16].

III. Mixed mode solar dryers

Om Prakash and Anil Kumar reviewed the different green house solar dryers and found that the PV-operated forced convection green house solar dryer was best for the crops having high moisture content where as natural convection mode green house dryer was applicable for the crops having less moisture content [17].

B.K.Bala and Serm Janjai developed the tunnel type solar dryer consists of the polythyn UV stabilized sheet and black absorber surface operated by four PV-panel operated fans. The Bombay duck fish which contain 90 %(w.b.) Moisture content is consumed in dried state by many people in world. The 150Kg of Bombay duck fishes are dried in the tunnel type dryer under the forced convection mode and it dried in 9h and the fish which kept in the open sun dried in 15h. Also the quality of the dried fish inside the tunnel dryer is great as compared to the open drying as well as the drying period was less in tunnel dryer [18]. MD.Shaheed Raza et al done the quality analysis of the different fishes after being dried and concluded that the fish which are to be dried in the newly developed solar tunnel dryer had great quality in terms of protins, vitamins and colours. Also dryer can be economically viable for the fisherman as large quantity of fishes can be dried in small area with in less drying time as compare to the open sun drying [19].

G.M.Kittu et al Tilapia fish were dried in the developed solar tunnel dryer. It is observed that during experimentation the relative humidity inside the dryer is continuously decreasing hence equilibrium moisture content can be neglected from the equation of the moisture ratio. The simulation has been done to predict the moisture ratio and is well matched with the experimental results. Mathematical model is developed in visual basic 6 to predict the plenum chamber different characteristics [20]. F.K.Forson et al provide the better design and thumb rule for the mixed mode natural convection solar dryer. The complete design of the solar dryer is done based on the drying requirements of the food items to be dried and the atmospheric condition [21]. M.S.Sevada gives the proper design of the walk- in type hemi cylindrical solar tunnel dryer for drying of the dibasic calcium phosphate for industrial purpose. The collector area is determined as the function of the drying requirement and north wall of the dryer is insulated although UV stabilized polythyne sheet was used for making of the tunnel type dryer [22].

D.K.Rabha and P.Muthukumar gives the performance studies of the forced convection solar dryer integrated with the paraffin wax based latent heat storage medium for the operating of the dryer after the sun shine hours. The exergy and energy analysis was done by drying of 20Kg red chillies. The 20Kg chillies were dried in the solar dryer after four consecutive days [23]. H.H.Chen et developed the closed type solar dryer for drying of the lemon slices and compare with the open sun drying and hot air dryer the different color values, white index are determined and concluded that designed system produce high quality products and makes efficient use of the solar energy [24].Mixed mode solar dryer was developed for fish drying and analysed with bombay dick fish[27].

IV. CONCLUSION

Many types of new and innovative design of the solar dryer had been studied specially in the case of the indirect mode and mixed mode solar dryer. It can be concluded that the mixed mode solar dryer can be more effective as compared to rest of the dryers. The no load performance index as well as the drying performance and capabilities of that dryer is highest among rest of the dryer. For the efficient and economically drying of the fishes tunnel type dryer is best which is the most efficient in the natural convection mode also.

V. FUTURE SCOPE

From the brief literature analysis the indirect tent type or indirect tunnel type dryer may be developed which is generally mixed mode dryer. The absorber plate may be attached to the tunnel type dryer to increase the efficiency for it.

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