Exergy Analysis on Performance of Groundnut Solar Dryer with Forced Convection

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Abstract. The moisture present in the farming yields and in seeds is one of the greatest affecting factors which are playing a major role in storing it for longer days. The quality of products can be increased by preventing the formation of bacteria, yeast, etc. The moisture content present in the groundnut must be between 10 to 15% (weight basis). In this study a numerical analysis was investigated on a solar dryer, which is used to diminish the moisture content present in the groundnut to preserve it for longer days. The performance analyses of forced convection solar dryer with dryer compartment were analysed based on local ambient conditions at sathyamangalam for various required design and operating parameters such as moisture removal rate, air mass flow rate, air inlet, and outlet temperature. The proposed basic solar collector aperture area is about 2 m² which is made of the copper plate as an absorber plate coated with black powder coating for better absorption. The moisture content present in the freshly harvested groundnut varies from 25-30 % (weight basis). The analysis was done for drying groundnut to remove the moisture content to the required moisture level of 10% by utilizing solar energy. The results from the study illustrate that the Efficiency of dryer is a maximum of 39.2% for the optimized mass flow rate of 0.022 kg/s and also it was found that the dryer overall efficiency and average collector temperature is gradually decreasing for increasing the mass flow rate.

Keywords: Energy; uncertainty; Efficiency; Moisture; Heat gain

Nomenclature

| Symbol | Description |
|--------|-------------|
| t      | Time, hour  |
| I      | Radiation, W/m² |
| T_a    | Ambient temperature, K |
| T_a1   | Inlet air temperature, K |
| T_ab   | Average absorber temperature, K |
| Q_l    | Heat loss, W |
| Q_in   | Heat absorbed, W |
| T_a2   | Outlet air temperature, K |
| Q_u    | Heat gain, W |
| E_s    | Total input energy, W |
| ΔE_loss| Energy loss from the dryer to the ambient air, W |
| w_b    | Work done for blower, W |
| ρ_a    | Density, kg/m³ |
| η      | Efficiency, % |
1. Introduction

Drying was the first method for preserving food items used by humans. It is the process in which farm products are preserved by removing the moisture content with the help of solar power. This manner of preserving helps us to store the items for a longer period of time. In earlier days food items are dried in open sun light by placing them over mats, roofs or ground. This open drying has many disadvantages like rain, heavy wind, sand dust, etc. Also wastage of food due to insects, birds, etc. These climatic and infectious risk causes deterioration and decomposition of food particles. Also it needs a vast area of land and more time duration. Tray dryers are equipment that is helpful in drying grains in spite of rain, wind, insects, birds and dust. Only minimum space is required for the installation of the dryer and also relatively less expensive when compared to traditional solar drying. The drying rate depends up on numerous constraints such as radiation from sun, surrounding temperature, speed of wind, humidity ratio and initial moisture content, crop varieties and product that is exposed to the radiation. Analyzing the performance of solar dryer can be done for the different operating and design parameters such as collector area, mass flow rate of air and tray design. The air temperature at entrance of drying chamber is increased by increasing the length of the drying chamber [1]. A newly designed solar dryer for drying the maize was utilized for analysing the performance of solar dryer at different angle of flat plate solar collector. The result shows that the more radiation input can be obtained at an angle of 45° in the solar dryer. Peak value of solar radiation can be occurred at 11am and then afterwards it gradually decreases [2].

Estimating the drying time of the green pea at different temperatures was analysed to obtain the required final moisture content. Maximum of up to 25% of moisture content has been removed from the green pea after 1 hour of drying at the temperature of 348K. From the result it was found that the drying time increases when the inlet temperature of drying chamber decreases [3]. Numerical analysis of the solar dryer was done for the different psychometric properties of air for the required output parameter dry food crops. The results shows that the dryer gives the better performance at optimized operating parameter of input temperature of about 32°C and relative humidity of 80%, the output temperature of about 45°C and relative humidity of 40% [4]. The solar dryer with mixed-mode was fabricated and an experimental study also been done on the dryer in which the results shows that the efficiency and product drying rate was 57.5% and 0.62 kg/h respectively [5]. Design and development of the setup of solar dryer to analyse the performance of dryer at different temperatures by drying potato slice was done. The performance analyse of the dryer was done for the moisture content in the potato slice at different temperatures such as 40°C, 50°C, 60°C and 70°C at constant mass flow rate of air and at the efficient performance of the dryer the moisture content can be reduced from 85% to 21% [6]. Various design and fabrication models were discussed for
effective performance of the solar dryer for drying applications. The collector area of the dryer for the mass of the drying products were also been compared for different required and ambient conditions [7].

A brief Discussion were also been made about different types of solar dryers in which the difference between the natural and forced convection of the solar dryer were elaborately discussed with the cost efficient types of solar dryers for farmers in rural areas [8]. The novel solar drying system is designed and the performance of the system was evaluated for drying seaweed for the moisture removal of 90% (wet basis). The results show for the optimized drying time, air flow rate, the efficiency of the collector was 35% with the best payback period of 2.33 year [9]. An elaborated study also been done on various solar dryers with respect to the drying product, performance and economical availability of the dryer [10]. A new unsteady state analytical model was derived for an inclined multi-pass dryer in which a deep-bed dryer attached with in-built thermal storage. The performance of a solar air heater was evaluated for the rate of moisture rate and air humidity [11]. An experimental study was conducted on the performance of solar dryer with solar tracking system to examine the enhancement on the dryer performance with respect to the fixed and tracking position. The result shows that the dryer performance is enhanced to 75% from 52% by tracking the sun instead of fixed in a position [12]. Performance analysis was done on the greenhouse solar dryer for ginger drying with parabolic roof structure enclosed by polycarbonate plates with the base area of 912.4 m² [13]. A novel active indirect solar dryer was developed and performance study also been done for banana drying application. The dryer efficiency was found to be in the range of 13.85 to 31.84% [14]. A brief review on economic analysis and significance of structural factors on the design of solar dryers was discussed based on the various drying applications and technologies in the selected Asian countries [15].

The PV/T drying system was designed and fabricated for finding the performance of the closed-loop control unit assisted solar dryer for enhancing the drying rate [16]. The mathematical modelling also been done for finding the thermal buoyancy in the convection on solar dryer for various inlet opening to vent outlet opening ratios [17]. A novel hybrid solar-biomass dryer is designed and fabricated for finding the energy and exergy efficiency of the dryer. The results show that the collector efficiency is in range of 21% to 22% for the effective design and operating parameters [18]. A novel solar indirect dryer is designed and developed which chimney and powered fan. The result shows the significance of the design and operating parameters on the maximum average temperature for the optimized value of 4.3°C [19]. An experimental study on solar dryer was done to investigate the moisture deduction rate in three unlike chambers (chimney type, attic space type, thin tube chimney type). The results shows that the moisture removal rate in three different chambers were 44.5%, 33.3% and 58.9% for chimney type, attic space type and thin tube chimney type respectively [20]. Adaption of packed bed design of absorber plate were also been done on the solar dryer for enhancing the exergy. A novel thermal energy storage system supported solar dryer with was designed and developed for bitter gourd drying application. An exergy and environmental analysis was done for evaluating the thermal performance of solar dryer different design and operating parameters. The mass flow rate were also been optimised for the better moisture removal rate and efficiency [21-22].

In this present study, the design and development of solar flat collector dryer was done to find the enhancement of the thermal performance of the dryer system by adapting the black powder coating absorber copper plate for better absorption. The significance of the moisture content present in the fresh harvested groundnut on the thermal performance of the dryer system also been investigated. The experimental analysis were also been done for drying the groundnut to remove the moisture content to the required moisture level by utilizing the solar energy. The effect of mass flow rate on performance of dryer is also to be found for optimizing the dryer overall efficiency and average collector temperature at maximum.

2. Experimentation:
The design of solar dryer was based on the maximum requirement and utilization of the solar input and heating output energy. The dryer consists of a flat plate collector of aperture area of 2 m² (2 m x 1 m) and forced convection system which is assisted with an air blower. The dryer setup consists of 3 major parts namely flat plate collector, tray drying unit and natural draft system. Figure.1 shows the drying compartment and tray setup (0.6 x 0.5 m, 3 No’s) design which is entirely insulated with glass wool and the Figure.2 represents the design of solar collector area and blower setup with natural chimney draft. The collector setup is inclined to the horizontal surface at an angle of 25° which is attached in front of the drying unit for the maximum collection of solar radiation. The air blower is attached for the suction of air and to blow the air at the required velocity to the collector. A regulator is also fixed with the blower for regulating the flow rate of the air. The additional secondary reflector mirror setup (0.7 x 0.6 m) is provided to increase the received solar flux in the copper plate in the solar collector. The natural draft chimney is designed in a way to provide more pressure difference on the compartment tray for the flow of air which is shown in Figure.3.

![Figure 1](image1.png) ![Figure 2](image2.png)

To increase the absorptivity of the copper plate in the solar collector section, black powder coating (absorptivity of 0.95) was given to the plate. The aluminium foil is used as a secondary reflector (reflectivity of 0.9) at the vertical surface of the drying compartment tray for enhancing the optical efficiency of the solar dryer. The acrylic cover (transmissivity of 0.9) is provided at the solar collector as a transparent medium which replaces the glass materials for better economic of the solar dryer.
The dryer operating parameters are confirmed for its steady state conditions while the experimentation study is started for finding the output parameters. The operating parameters were taken for a day from 10.00 AM to 03.00 PM within the interval of 10 minutes. The corresponding values of the direct radiation and temperatures at various nodes (atmospheric, copper plate, transparent cover, air inlet and outlet) were noted and it is shown in Table 1. All the readings were taken at the steady state conditions for various flow rate of air which is blown into the solar collector area.

Table 1. Experimental parameters.

| T (hr) | I (W/m²) | T_a1 (K) | T_ab (K) | T_a2 (K) |
|-------|----------|----------|----------|----------|
| 10    | 790      | 304      | 322      | 306.1    |
| 11    | 816      | 305      | 324      | 308.2    |
| 12    | 873      | 307      | 328      | 310.3    |
| 1     | 852      | 306      | 325      | 309.1    |
| 2     | 825      | 305      | 322      | 307.9    |
| 3     | 798      | 305      | 320      | 307.2    |

3. Analyzing methods:

3.1. Dryer efficiency:

Moisture content in 1 kg of ground nut is denoted by M_m and Moisture ratio (M_r) is given by following equation (Eq. (1)).

\[ M_r = \frac{M_m}{m_i} \]  
(1)
Dryer instantaneous efficiency and moisture removed by the dryer are given by following equation (Eq. (2) & (3)) respectively.

\[ \eta = \frac{Q_d}{E_s} \]  

(2)

\[ m_e = m_f - m_i \]  

(3)

Dryer instantaneous total energy supply, solar flux received and optical efficiency of the collector are given by following equation (Eq. (4) & (5) & (6)) respectively.

\[ E_s = (I \times A) + w_b \]  

(4)

\[ E_4 = \tau \times \alpha \times \varepsilon (I \times A) \]  

(5)

\[ \eta_{op} = \frac{E_s}{\tau \times \alpha \times \varepsilon (I \times A)} \]  

(6)

Energy balance: Energy in to the collector = Energy out from the collector

\[ E_4 = E_{in} = E_{out} = (mc_p\Delta T)_{plate} + (mc_p\Delta T)_{air} + \Delta E_{loss} \]

\[ E_4 = [m_a c_p (T_{a2} - T_{a1})] + [m_a c_p (T_{a2} - T_{a1})] + \Delta E_{loss} \]

Dryer instantaneous energy given to the drying product for moisture removal and Dryer instantaneous efficiency are given by (Eq. (7) & (8)) respectively.

\[ E_5 = E_4 - \left( [m_a c_p (T_{a3} - T_{a2})] \right) \]  

(7)

\[ \eta_d = \frac{E_5}{E_4} \]  

(8)

Dryer instantaneous energy given to the drying product in the mode of convective heat transfer for moisture removal rate which is equal to the sensible heat loss by the air is given by (Eq. (9)).

\[ Q = \dot{h}A(T_a - T_p) \]  

(9)

\[ m_a c_p (T_{a1} - T_{a2}) = \dot{h}A(T_{ab} - T_a) \]

The average temperature and heat gain of the dryer are given by (Eq. (10) & (11)) respectively.

\[ T_{avg} = \frac{T_{ab} + T_a}{2} \]  

(10)

From Equation (9) & (10),

\[ \Delta T_{ab} = \frac{\dot{h}A(T_a - T_{a2})}{m_a c_p} \]

\[ Q_{ua} = \frac{m_m x h_f g}{c} \]  

(11)

3.2. Uncertainty analyses in solar dryer:
The uncertainties on the measuring parameters are tabulated in Table 2 and the same values are used to find the uncertainty on the efficiency of the solar dryer which is given by (Eq. (12))

Table 2. Uncertainty parameters.

| Notation | Description                  | Specification |
|----------|------------------------------|---------------|
| UT       | Thermocouple                 | ±0.5°C        |
| URH      | Relative humidity thermo hydrometer | ±1%         |
| UV       | Anemometer                   | ±0.1 m/s      |
| UI       | Solar power meter            | ±5 W/m²       |
| UW       | Weighing machine             | ±0.001 kg     |

\[
u_n = \sqrt{\left(\frac{\partial n}{\partial m}\right)^2 U_7^2 + \left(\frac{\partial n}{\partial T_c}\right)^2 U_{R_H}^2 + \left(\frac{\partial n}{\partial T_c}\right)^2 U_{U}^2 + \left(\frac{\partial n}{\partial T_c}\right)^2 U_{I}^2 + \left(\frac{\partial n}{\partial T_c}\right)^2 U_{W}^2} \quad (12)
\]

4. Result and Discussion

The average temperature of the solar dryer was calculated for different flow rate of air from the blower. Figure 4 shows that variation of average temperature of the collector with respect to different mass flow rate of air. Initially for the fully opened blowing condition of 0.044 kg/s, the collector average temperature is 312.4 K, whereas diminishing the mass flow rate of air leads to increasing the average temperature of the collector. The maximum average temperature is around 322.3 K at the optimized mass flow rate of 0.022 kg/s.

Figure 4 Variation on dryer average temperature with different mass flow rate
Figure 5 shows that variation on efficiency for different mass flow rate of air in the dryer. The maximum efficiency of about 40% is obtained at the mass flow rate of 0.022kg/s. The efficiency is further drops when mass flow rate increases and it reaches to 20% for the mass flow rate of 0.044kg/s and the efficiency is also decreases when the mass flow rate less than 0.022kg/s.

Figure 6 shows that heat loss and heat gain for various mass flow rate of air in the dryer. The dryer heat gain is about maximum, for the mass flow rate of air at 0.022kg/s and the value of the maximum heat gain of the dryer is about 725W. The heat gain is further decreases to 425W for the mass flow rate of air at 0.044kg/s. The heat loss is about maximum for mass flow rate of 0.044kg/s due to availability of time is very less which is not enough to conduct the heat from air to grains. Figure 7 shows the amount of moisture content removed for various mass flow rate of air at dryer. At the mass flow rate of 0.022kg/s, the reduction on moisture content is more when compare to the mass flow rate of 0.044kg/s for the same time interval. The amount of reduced moisture content is decreasing at increasing time interval from initial to 7 hours.
Figure 7 shows the reduction in moisture content with respect to drying time.

Figure 8 shows the operating parameters for mass flow rate of 0.022 kg/s.

Figure 8 shows the temperatures at various nodes with respect to time. The Ambient Temperature at 10 AM is 304K and it gradually increases to the maximum temperature of 307K at 12 noon and then decreases to 305K at 3 PM. Absorber plate Temperature at 10 AM is about 322K and it gradually increases to the maximum temperature of 328K at 12 noon and then it gradually decreases to 319K at 3 PM. Collector air inlet Temperature at 10 AM is about 304K and it gradually increases to the maximum temperature of 307K at 12 noon and then it gradually decreases to 305K at 3 PM. Collector air outlet Temperature at 10 AM is about 306K and it gradually increases to the maximum temperature of 310K at 12 noon and then it gradually decreases to 307K at 3 PM. Radiation at 10 AM is 782 W/m² and it gradually increases to the maximum radiation of 870 W/m² at 12 noon and then gradually decreases to 798 W/m². Figure 9 shows that instantaneous efficiency of the dryer at different times for the fixed mass flow rate. The efficiency is about maximum of 44% at noon due to the availability of maximum radiation and then efficiency is gradually decreases to 25% at 3 PM.
5. Conclusion

In this present study, the design and fabrication of secondary reflector assisted solar dryer was done with forced convection system and the performance of the solar dryer is analyzed for various mass flow rates of air, radiation and time interval. The mass flow rate of air across the dryer is varied from 0.022kg/s to 0.044kg/s and the maximum efficiency of dryer is obtained at the mass flow rate of 0.022kg/s at 12 noon. It was also found that the efficiency of the dryer is further decreases when the mass flow rate is increases from 0.022kg/s and the efficiency of the dryer is further decreases when the mass flow rate of air is decreases lower than 0.022 kg/s.

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