ABSTRACT

Drying is the most common method of preservation of medicinal plants and herbs. It is also an energy intensive operation and involves high cost for its processing. Conventional drying methods such as open sun drying and conventional fuel dryers are not suitable; since they may yield a less quality product and/or may increase the drying cost and/or time. Moreover, they may not be reliable and environmentally safe. Therefore, the trend is toward using controlled nonconventional drying methods to improve the quality of the product to be dried and at the same time to decrease the drying cost and time. These methods use renewable energy sources for their operation. Conventionally, low drying temperatures between 30 and 50° C are recommended to protect sensitive active ingredients. The use of solar dryers in the agricultural area to conserve vegetables, fruits, medicinal plants and herbs has shown to be practical, economical and the responsible approach environmentally. The solar drying systems can improve the quality and life of the dried product by retaining its essential content.

Therefore, in this study, an indirect forced convection solar dryer with and without the integration of biomass back up heater to dry the Coleus forskohlii stems and roots has been fabricated and investigated under the prevailing climatic conditions of Rasipuram, Tamil Nadu, India. The solar drying system consists of a flat plate air collector, drying chamber, biomass unit, and a centrifugal blower. A forced draught 0.1 kW centrifugal blower was used to supply the ambient air at the required the flow rate. A single-pass, single-glazed, the conventional solar air collector was used for gaining useful energy from the incident solar radiation. The drying chamber was fabricated using wooden materials with insulated inner walls. A down draft small capacity biomass gasifier was fabricated and used in this study.
The experiments were conducted in four different modes: a) open sun drying, b) forced convection solar drying, c) biomass assisted forced convection solar drying, and d) drying using of coleus roots and stems using biomass energy only. The mass flow rate of air varied from 0.01 to 0.03 kg/m²s for all forced convection solar drying experiments. During the integration of biomass heater with the solar drying when the solar radiation falls below 200 W/m² or during off sunshine hours, the mass flow rate was kept as 0.02 kg/m²s with varied temperatures of 40, 50 and 60°C respectively. Also, while drying only with biomass energy, the mass flow rates of air were varied between 0.01 and 0.03 kg/m²s with a temperature of 40, 50 and 60°C.

The temperature variation of ambient air during summer was recorded as 32 to 38°C and in winter it was about 28 to 35°C. The maximum solar radiation incident on the surface during the summer was 990 W/m² and during winter was about 969 W/m². The maximum temperature of the absorber plate rose to 103°C when the solar radiation level was at its peak. The trend of solar radiation and the average absorber plate temperature variation over time during the day time was almost similar. The maximum collector outlet air temperature of 66°C and 52°C at 0.01 and 0.03 kg/m²s respectively were obtained during experimentation and was suitable for grain drying applications.

The average collector efficiency of about 62.01% was obtained with a mass velocity of 0.04 kg/m²s. The average collector outlet temperature and the efficiency intersect at a mass flow rate of 0.023 kg/m²s. A 20 kg of fresh samples of unsliced and sliced roots with 10mm thickness and 10 kg of stems cut to a length of approximately 40 mm length were used in the drying experiments. The initial moisture content of coleus roots and stems on wet basis were about 85.7% and 90% respectively. The equilibrium moisture content on wet basis of roots was 11% and the stem was 12%.
In the open sun drying, the unsliced roots dried in 122 hours and the sliced roots dried in 93 hours, whereas the stems dried in 126 hours to reach its equilibrium moisture content. While drying under forced convection solar drying, the sliced roots dried within 32, 29 and 26 hours, the unsliced roots dried within 42, 40 and 34 hours and the stems took 54, 50 and 49 hours respectively at 0.01, 0.02 and 0.03 kg/m²s. The drying was faster at 0.03 kg/m²s than other two mass flow rates for stems and roots. The pickup efficiency of the air was about 25% for stem, 22% for unsliced root and 18% at 0.01 kg/m² and got reduced at higher mass flow rates.

In biomass assisted forced convection solar drying, the drying temperature during biomass assisting was maintained at 50°C. The drying time under forced convection solar drying with the integration of biomass backup heating after sunshine hours at 0.01 kg/m²s and 50°C was about 22 hours for stems and 19 hours for unsliced roots and 16 hours for the sliced roots. The difference in drying time for other two mass rates was only about two hours. The pickup efficiency value for this case was almost similar to that of forced convection solar drying because the initial stage of drying was done with indirect solar heating.

While drying was carried out using biomass energy alone, the stem dried within 14 hours at 40°C, 13 hours at 50°C and 10 hours at 60°C respectively at a mass flow rate of 0.01 kg/m²s. Similarly for other mass flow rates with the same level of temperature variations the unsliced root took a maximum time of 12 hours and a minimum of 7 hours with just an hour difference. The same way the sliced roots dried at a maximum of about 10 hours and a minimum of about 6 hours. The pickup efficiency of the drying air at 0.02 kg/m²s was about 32% for stem, 36% for sliced root and 30% for unsliced root.

The drying was quite faster in case of drying using biomass energy when compared to the other modes of drying and this is due to the fact that
the temperature of the drying air is constant throughout the process. With the inclusion of biomass energy in the forced convection solar drying process the drying was completed within a day, but whereas in forced convection solar drying it varied between 3 and 7 days. In case of open sun drying the drying took about 15 days for stems and unsliced roots.

For all the modes, the drying took place only in the falling rate period and no constant period of drying was observed. Drying curves obtained from forced convection solar drying, biomass assisted forced convection solar drying and drying using biomass energy were fitted into thirteen different thin layer models by applying the non-linear regression analysis technique. All the models were compared in terms of to three statistical parameters, i.e., correlation coefficient ($r$), Root Mean Square Error (RMSE) and reduced chi-square ($\chi^2$) between the observed and the predicted moisture ratios. The seven models that predicted higher coefficient of correlation with more than 0.9 were taken into consideration. According to the results, Wang and Singh drying model could satisfactorily describe the forced convection solar drying curve with a correlation coefficient ($r$) of 0.9996 and reduced Chi-square ($\chi^2$) of 0.0001 for coleus sliced roots and $r = 0.9992$ and $\chi^2 = 0.0002$ for unsliced roots. Logarithmic model was found to be the best model for describing the drying behavior of stems with $r = 0.9979$ and $\chi^2 = 0.0003$. In biomass assisted forced convection drying of coleus roots and stems, the same Wang and Singh and Logarithmic model found to have the best fit. In case of drying only with biomass energy, the Page model resulting in the highest “$r$” and lowest RMSE and $\chi^2$, and hence the best model to describe the solar-drying characteristics of Coleus roots and stems.

The economic aspects of the solar dryer and the monetary savings obtained by the fuel reduction are also discussed. Economic analysis indicates that the solar drying system is economically viable and cost effective with a payback of less than 3 years.