A REVIEW ON SOLAR BIOMASS HYBRID DRYER

Mr. Kishor M. Mahajan[1], Dr. Vijaykumar H. Patil[2], Mr. Tushar A. Koli[3]

Article History: Received: 19.04.2023 **Revised:** 04.05.2023 **Accepted:** 20.06.2023

Abstract

Open-sun drying is a primitive food preservation technique. Also, solar dryers of various designs, capacities, and sizes have been developed by the agricultural processing industry. There are some limitations for the solar dryers, like intermittent solar radiation throughout the day, unavailability at night, and seasonal variation in intensity; hence, continuous drying is not possible with them. Continuous drying of agricultural produce can be achieved through a combination of solar and auxiliary heating sources in a mixed-mode system. Biomass is the most widely used auxiliary heating source due to its availability and low cost in rural areas of developing countries. Until now, many researchers have designed, constructed, and examined the Solar Biomass Hybrid Dryers (SBHD). The solar biomass hybrid dryer is one of the most noticeable dryers used to dry agro products. Different designs for drying different products have been developed and tested experimentally by the researchers, and the results have been validated with software like CFD (Computational Fluid Dynamics) and Ansys. Mathematical models like the page model and modified page model have been developed for predicting the drying results. The purpose of this paper is to review the design features, construction, and experimentation carried out over SBHD by different researchers, and summarize their findings to provide a basis for new developers.

Keywords: Solar assisted, Biomass, Hybrid dryer, Turmeric Rhizomes

[1]PhD Scholar, Department of Mechanical engineering, GF's GCOE, Jalgaon KBCNMU, 425003, India
[2]Professor, Department of Mechanical engineering, GF's GCOE, Jalgaon, 425003, India
[3]Assistant Professor, Department of Mechanical engineering, GF's GCOE, Jalgaon, 425003, India

Email: [1]mahajankishor87@gmail.com

DOI: 10.31838/ecb/2023.12.s3.814

1. Introduction

Introduction:
Drying:
Drying is a method of preservation in which water is removed from the food in order to prevent bacterial growth. It is a complicated process with unsteady heat and mass transfer and also having physical and chemical transformations involved that affect the product quality. Due to heating, there is a simultaneous heat and mass transfer in drying, by which the moisture is removed. [1]

Drying Methods:
There are various drying methods available, as mentioned below. [2]

i. Convective Drying
ii. Dielectric Drying or Microwave Drying
iii. Freeze Drying
iv. Natural Air Drying or Open Sun Drying (OSD)
v. Solar Drying

Open Sun Drying:
In recent decades, solar drying has become very popular and is frequently used for drying. In open sun drying, the food is dried in open air. OSD is the ancient and very traditional method of drying in which the product or material to be dried is spread over the ground on mats or trays and allowed to dry throughout the sunshine hours. Solar energy is amply available, free, and pollution-free energy source.

Disadvantages of OSD:

i. Due to dust, dirt, and pollution, food materials get easily contaminated.
ii. The material to be dried gets damaged by animals, birds, or insects and their droppings.
iii. There is degradation of the product to be dried due to direct sun radiation, storms, and dew.
iv. OSD results in insufficient or uneven drying, which causes additional loss of material during storage.
v. There is spoilage of material due to infestation by fungi, bacteria, and other microorganisms. [3]

Solar Dryers:
In solar dryers, the material is dried in controlled conditions, and these are mainly used for drying fruits and vegetables. The final product from a solar dryer is clean and hygienic. A solar dryer occupies less space and saves energy. There is no need for any external fuel to be burned in solar dryers, hence they are pollution-free. Solar drying improves the stability of the product and also reduces its weight and, thereby, its shipping cost. In spite of their many advantages, solar dryers also have some drawbacks.

Limitations for Solar Drying: [4]

i. Solar dryers can only be used where there is an adequate amount of solar radiation.
ii. Solar dryers cannot be used at night.
iii. Sunshine hours are not constant; they vary from month to month.

Necessity
Need of Hybrid Dryer:
As solar radiation throughout the day is not constant, it is intermittent; therefore, continuous drying is not possible with solar dryers. To make the solar dryer ready for continuous drying, a combination of solar and non-solar heating sources in a mixed mode is essential. In a mixed-mode (hybrid) system, to increase efficiency, we can store thermal energy available during the daytime and use it during the off-sunlight hours. Also in a mixed-mode system, auxiliary heating sources like electric resistance heaters or biomass burners are used to provide a continuous supply of hot air to the drying chamber during the night and in a cloudy atmosphere. Thus, the combination of the auxiliary heating sources with the solar dryer is needed to achieve continuous drying of the agro products. [5]

Significance of Solar Biomass Combination:
In rural areas of developing countries, biomass is easily available and cost-effective. The efficiency of agro dryers could be improved by using a combination of solar and biomass as a heating source, compared with using only solar or biomass as a heating source. The combination of solar and biomass dryers has the ability to increase productivity and is also economically viable for small and medium-scale agro-processing industries in developing countries. A country like India, which has ample quantities of natural resources like forests, agricultural waste, and solar radiation, could make effective use of hybrid dryers.

Aims of the Study:
The intention of this review is to study the design and constructional features, materials used for construction, product drying, experimentation, and performance comparison of different SBHD developed by different researchers. This study will be the basis for new developers of SBHD to compare their design and performance with the existing one.

2. Methods

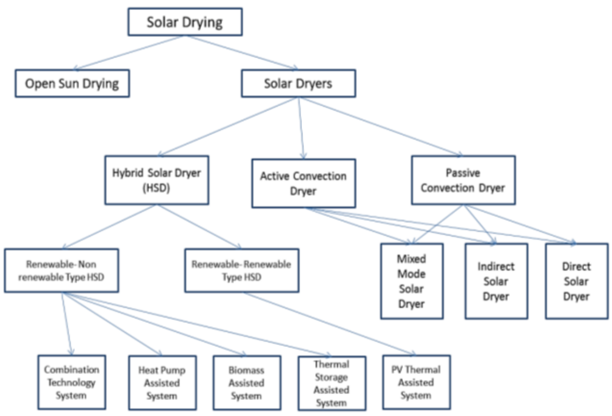
Objective of the study:
The aim of this revision is to know the design and constructional features, as well as the materials

used for construction, of the SBHD as determined by different researchers. Also, this study has concerns about the different products dried in the SBHD and the performance analysis of the drying parameters. This review covers the experimental analysis, optimisation, modelling, and simulation done by the different researchers and highlights their findings.

Design and setting of the study:

Normally, hybrid drying methods comprise processes that employ more than one dryer or multiple modes of heat transfer, as well as those that use two or more stages of drying to attain the desired dryness, product quality, drying time, and manufacturing output. There are many types of hybrid dryers available with combinations of different drying modes. The main focus of this review was to study the design, construction, and experimental results of the solar-assisted biomass hybrid dryer only. For this study, the key selection criteria for the research paper were the combination of solar energy and biomass energy in a hybrid dryer for drying agricultural products. The papers were selected by using key words like solar assisted, biomass hybrid dryer, and "experimental analysis of hybrid dryers." Using the key words for the search, many research papers for the hybrid dryers were openly available from reputed journals, out of which only the research papers having a combination of solar biomass were selected for the study. This study was a re-analysis of existing data, which is openly available at locations cited in the reference section. The systematic reviewing method was used to conduct the study and analyse the numerical data from the observations. The study was categorised according to the special design features, constructional features, product dried, and comparative experimental analysis of the dryer with the OSD. Also, the study is associated with the validation of experimental results by using software like CFD and Ansys. The prediction of the drying results using mathematical models like the page model and modified page model has also been revealed. The results for the different SBHD, in terms of special design features, product dried, time taken in OSD, time taken with SBHD, and distinct performance remarks, have been highlighted at the end.

Classification of Solar Dryers



The solar dryers are broadly classified into three categories: hybrid solar dryers, active (forced) convection dryers, and passive (natural) convection dryers. Hybrid solar dryers (HSD) can be divided into two categories: renewable-nonrenewable type and renewable-renewable type. In the renewable-renewable type, both the sources of heating are renewable, and in the renewable-nonrenewable type, along with the solar heating, a secondary nonrenewable source of heating is employed. The secondary non-renewable source may include a heat pump, biomass, or a thermal storage system. [6]

Constructional Features and Performance Analysis of Solar Biomass Hybrid Dryer Systems: A Review

Hybrid Solar-Biomass Dryer with an Automatically Controlled Gasifier Stove

M. K. Mishra et al. [7] designed, fabricated, and tested a hybrid solar-biomass dryer consisting of a solar flat plate collector, an automatically controlled gasifier stove, a cross-flow heat exchanger, and a dryer located above the heat exchanger. The biomass gasifier stove consists of four main parts, i.e., reaction chamber, fuel storage hopper, primary air inlet, and combustion chamber, as shown in figure 1.

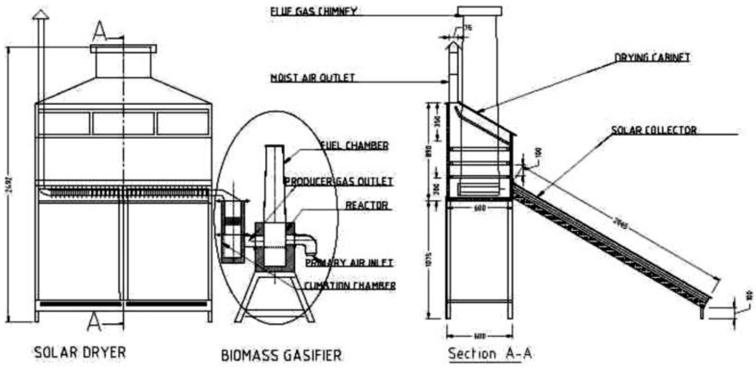


Figure 1. Diagrammatic sketch of hybrid solar-biomass dryer

Wooden blocks were used as fuel for the gasifier stove. Experiments were conducted on drying chilli and banana. Ripen chilli of 16 kg., with an initial moisture content of 72.58% wb (wet basis), was dried to a moisture content of 7.13% wb within 20 hours, whereas it takes 48 hours in open sun drying during April in Kathmandu. The overall efficiency of the dryer was estimated at around 4.29%. Operation of the dryer in hybrid mode saves 15% fuel in comparison with operating with biomass fuel alone.

4.2 Solar Assisted Heat Pump Dryer Integrated with Biomass Furnace

The design, performance, and evaluation of a solar-assisted heat pump dryer integrated with a biomass furnace for drying red chilli were done by **M. Yahya** [8]. The drying system consists of a collector array, heat pump, biomass furnace, drying chamber, and blower, as shown in Figure 2.

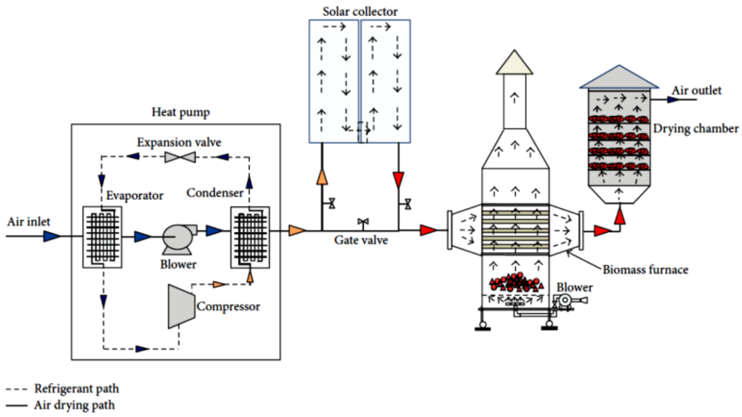


Figure 2. Schematic diagram of the solar assisted heat pump drying integrated with biomass furnace.

The inlet ambient air temperature is raised by the heat pump, and then it passes through a series of solar collectors, where it takes the heat from the absorber and gets heated. This heated air from the solar collector passes through the heat exchanger, where it gets heated again. The heated air from the biomass heat exchanger is supplied to the drying chamber, where drying takes place. The experimentation was done at Padang Institute of Technology, West Sumatra, Indonesia. The red chillies, weighing 22 kg and having an initial moisture content of 4.26 db (dry basis), were dried to a final moisture content of 0.08 db within 11 hours, while in OSD they need 62 hours. Compared with OSD, this dryer achieves an 82% saving in drying time. The average temperature, relative humidity, and air mass flow rate within the drying chamber during the test were 70.50 °C, 10.1%, and 0.124 kg/s, respectively. The experimental results show a drying rate of about 1.57 kg/kWh and a thermal efficiency of about 9.03%. The Newton, Henderson-Pabis, and Page models were fitted to the experimental data for red chilli drying. The coefficient of determination (R2), mean bias error (MBE), and root mean square error (RMSE) were compared to evaluate the performance of the mathematical models. The best result was given by the page model.

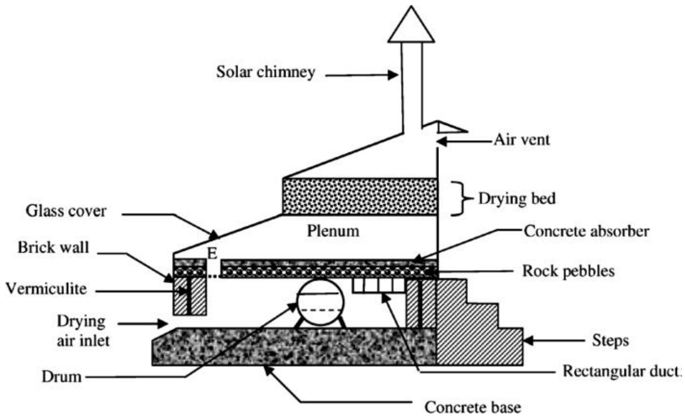


Figure 3. Cross-sectional view of the solar dryer through the burner, collector, drying chamber and solar chimney

An Indirect Type Natural Convection Solar Dryer with Integrated Collector-Storage and Biomass Backup Heater

A. Madhlopa and G. Ngwalo [9]. Designed, developed, and evaluated an indirect-type natural convection solar dryer with integrated collector storage and biomass backup heater. The main components of the dryer are the biomass burner, collector-storage thermal mass, and drying chamber with solar chimney (Figure 3). The experimentation was done in three different modes: solar, biomass, and solar biomass. Twelve batches of fresh pineapple were dried, each batch weighing 20 kg. During the drying process, metrological conditions were monitored. The thermal mass stores heat from solar and biomass air heaters and moderates the fluctuations in temperature in the drying chamber. The results showed that the solar mode of operation was slowest and the solar biomass mode was fastest in drying the samples. In solar biomass mode, the dryer reduced the moisture content of pineapple slices from about 669 to 11% (db). The final day moisture pick-up efficiency was found to be 15%, 11%, and 13% in the solar, biomass, and solar biomass modes of operation, respectively. During nocturnal drying, reverse thermosiphoning was observed in the solar chimney. Optimisation of the system and transparent insulation of the exterior surface of the solar chimney were suggested as improvements to avoid reverse thermosiphoning.

Figure 4. Left: Greenhouse Dryer. Right: The biomass heater for the hybrid dryer

A Gable Roof Greenhouse Solar-Biomass Dryer

Ndirangu, S. N et al. [10] designed and evaluated the performance of a solar-biomass greenhouse dryer for drying selected crops in western Kenya. A gable-roofed greenhouse solar-biomass dryer, shown in Figure 4, has a biomass heating system that backs up the solar energy. There are four provisions for air ventilation: chimney, turbo ventilator, lower opening, and fans. For the test trials, six common crops—arrow roots, cassava, sweet, kales, banana, and spider plants—were utilised. The experimentation was carried out under three modes of operation: natural ventilation, forced convection, and solar biomass hybrid mode. Following are the observations recorded during experimentation.

Table 1. Results of gable roof greenhouse solar-biomass dryer

Measured parameter	Mode of operation		
	Natural	Forced	Hybrid mode
The difference between the inside of the dryer and ambient temperature	13.1°C	20.8°C	17.9°C
Inside dryer temperature	49.3°C	53.8°C	53.2°C

Average solar radiation	545 W /m^2	668 W /m^2	594 W /m^2
Relative humidity reduced during drying	21.5%	18.1%	19.5%
Ambient relative humidity	35.5%	44.0%,	35.3%
Monitored air velocity	-	0.4 m/ s	0.7 m/ s

No temperature difference was found between the lower and upper beds under the three modes. The overall efficiency of the study indicates that the efficiency of greenhouse dryers could be increased through improved ventilation and backup energy.

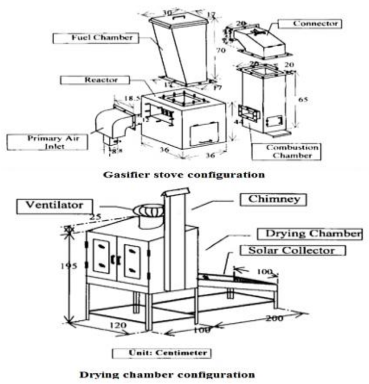


Figure 5. The Hybrid Solar/Biomass-Fuelled Drying System configuration

A Hybrid Solar Biomass Energy Powered Dryer for Drying Fruit and Vegetables

S.C. Bhattacharya et al. [11] designed, fabricated, and tested a hybrid solar biomass-powered dryer for drying fruit and vegetables. The dryer has five main parts: a flat plate collector, a biomass gasifier stove, a heat exchanger, a drying chamber, and a temperature control system, as shown in the figure. 5. The flue gases produced from the combustion of producer gas enter through the connector, and the heat exchanger located at the bottom of the drying chamber transfers the heat to the drying air. The heat exchanger used here is a natural draught cross-flow type. The dryer could be operated as a solar dryer during sunny days and as a hybrid solar biomass energy-powered dryer during cloudy days. The experimentation was carried out with banana and chilli (16 kg each batch) in biomass-fueled mode. Banana and chilli were dried from initial moisture contents of 67.4% and 71.2% (wb) to final moisture contents of 24.0% and 7.1%, respectively. The banana and chilli were also dried in the sun for comparison. For hybrid solar biomass mode, only chillies were dried from an initial moisture content of 72.6% (wb) to a final moisture content of 7.1% (wb). It has been observed that the required moisture content in hybrid operation (biomass-fueled dryer) was reached within 18 and 22 hours, respectively, for banana and chilli, while it needed 66 and 48 hours, respectively, for natural sun drying. With biomass energy mode alone, the drying duration and fuel consumption rates were about 20 hours and 2 kg/hr, respectively, for both banana and chilli.

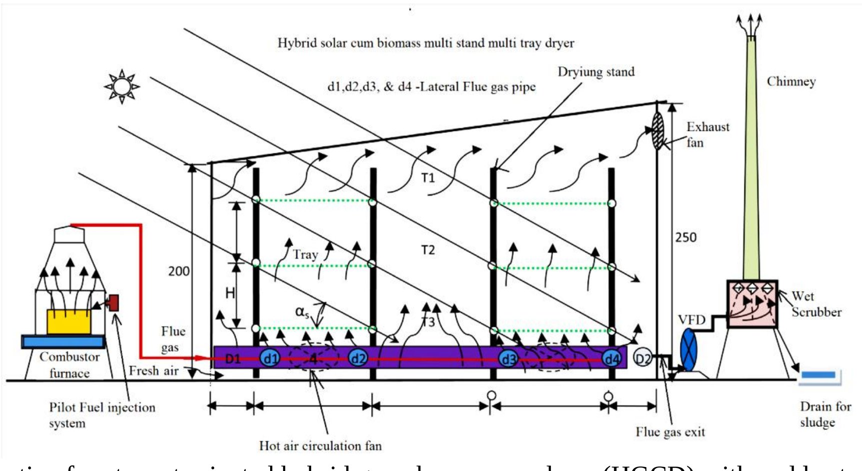


Figure 6. Schematic of east-west oriented hybrid greenhouse crop dryer (HGCD) with paddy straw biomass bale combustor furnace

A Solar Cum Biomass Hybrid Greenhouse Dryer Using Flue Gas Heat Transfer Network

V.P. Sethi and Mankaran Dhimanto [12], presented a solar cum biomass hybrid greenhouse crop dryer (HGCD) using a flue gas heat transfer network as shown in figure. 6. The dryer has a constant drying temperature of 62^0C and works on solar energy and biomass for 24 hours in continuous operation. A forced-draught straw bale compressor is employed to generate flue gas above 500 °C as a supplemental heat source and is attached to the flue gas heat transfer pipe network. Vertical clearance between two successive trays is optimised for selected latitudes of 30°, 35°, 40°, 45°, and 50°N. Global solar radiation and thermal models are established to forecast solar radiation availability and HGCD chamber air temperature (T_{hgcd}). For forced convection heating, radiation heating, and biomass heating, load requirements were projected through a developed heat transfer model. The developed thermal model predicted the T_{hgcd} of 26^0C to 38^0C equivalent to a heating load of 4–6.5 kW, when ambient air temperature continued to be between 10^0C and 18^0C at Ludhiana (30^0 N) in India. The heat transfer model anticipated about 26.2 kW and 13.4 kW of supplementary heat during severe and moderate night temperatures of -5^0C and 10^0C which can be met through complete combustion of 80 kg and 40 kg of paddy straw biomass per hour, respectively, to maintain T_{hgcd} between 60^0 and 62^0 C. The logarithmic drying model proved to be the best-fitting drying model for fenugreek drying. Monetary analysis shows that the suggested technology can recuperate its cost within 5 years and has great adaptability potential in terms of paddy straw management in India.

Figure **7.** Prototype of the indirect solar dryer

A Low-Cost Hybrid Solar Drying System

M.C. Ndukwu et al. [13], designed and fabricate a low-cost hybrid solar drying system and presented the drying kinetics, heat transfer coefficient and thin layer models for the dried product. The solar dryer one equipped with biomass heater (SD_1) and the other without biomass heater (SD_2) are shown in Figure 7. Experimental result showed that the developed solar dryer (SD_1) can save drying time from 27.78 % to 58.33 % in comparison with the open sun drying. During experimentation the ambient temperature was in the range of 30^0C to 40^0C and humidity was ranging from 55% to 70% and, under these conditions the SD_1 efficiency resulted in between 20.81 to 21.89%., heat transfer coefficient ranged from 0.64 to 10.9 W/m^2 ^{0}C. Verma et al. model given the best result for SD_1 while logarithmic model proved best for SD_2.

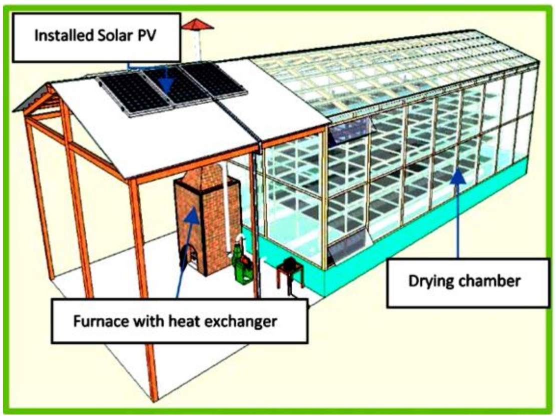


Figure 8. Solar Biomass Hybrid Dryer; schematic view

A 5.0-MT Solar Biomass Hybrid Dryer Containing a Solar Tent and a Furnace

A. Bosomtwe et al. [14], evaluated the effectiveness of a 5.0-MT Solar Biomass Hybrid Dryer (SBHD) containing a solar tent and a furnace (shown in figure 8) for thermal drying and disinfestation of maize. The fibreglass that was laid over a wooden frame to build this SBHD. The grains are dried over six levels of shelves to ensure the uniform drying. During seven hours experimentation following results noted in three different mode of drying.Table 2. Findings of 5.0-MT Solar Biomass Hybrid Dryer

Measured parameter	Mode of drying		
	SBHD	**SD**	**Laboratory**
Mean internal temperature	52.3°C	41.4°C	30.3°C
Temperature in cages	49.5°C	38.2°C	29.9°C
Reduction in moisture content	7.7 %	5.2 %	2.9 %
Grain moisture content reduction rate per hour	1.1 %	0.74 %	0.4 %

There was 100% mortality of S. zeamais and C. ferrugineus adults realised in only the SBHD; some immatures of all three species continued in all three manners. The survival rate of immatures was highest in the laboratory, trailed by SD and lowest in the SBHD for all three species. TDK % was higher in the SBHD (6.7 ± 0.9) than SD (3.3 ± 0.3) and laboratory (2.7 ± 0.3). These results show that the SBHD is effective for both drying and disinfestation of grain.

Joseph O. Akowuah et al. [15], investigated the effect of drying temperature on kernel damage and viability of maize dried in a Solar Biomass Hybrid Dryer having capacity 5-tonne. The SBHD haves greenhouse construction design with an overall dimension of 10.7 × 6.5 × 3.3 m. the dryer is partitioned into three internal drying sections i.e., the Right Section (RS), Left Section (LS) and a Middle Section (MS). Each section has four levels of drying shelves, which are arranged from bottom to top in order of Level 1 (L_1), L_2, L_3 and L_4 with corresponding heights (0.6 m, 1.2 m, 1.8m and 2.4 m) from the ground, respectively. The dryer is united with a biomass burner enclosed with a cross flow type heat exchanger (figure. 8). In this work, effect of air temperature in the dryer, on the physical quality, and germination of maize kernels, was examined. Maize grains were dried in the open sun drying and solar biomass hybrid dryer at 4 varying levels i.e. L_1, L_2, L_3 and L_4. The harvested maize has 22.8% moisture content and it was dried at the varying levels until it reaches the final desired moisture content of 12.8 % (wb). Results show that, air temperatures in the dryer increases with height. The lowest mean temperature of 44.4˚C recorded at L_1 and mean maximum of 52.8˚C at L_4. Drying temperature noted at L_1-L_3 and ambient had no substantial effect on kernel damage and viability. L_1 and L_3 were considered optimum for drying compared to the top most tray L kernel stress crack index was reduced on average by 14% and kernel germination increased by 33%. It proves the potential of the dryer to be used for commercial drying of maize grains and for seed production.

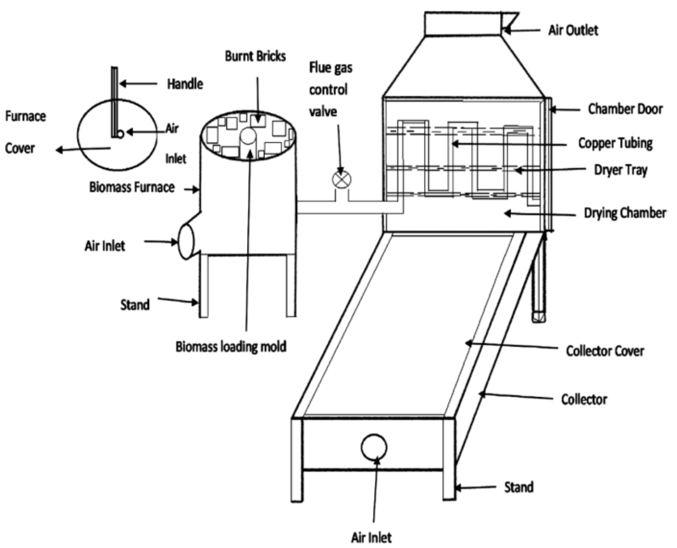


Figure 9. Schematic View of the prototype of the indirect solar dryer with biomass Furnace

Exegetic Sustainability of a Hybrid Solar Biomass Dryer Integrated with Copper Tubing

M.C. Ndukwu et al. [16], have investigated the exegetic sustainability of a hybrid solar biomass dryer integrated with copper tubing as a heat exchanger. A schematic view of the designed solar dryer with biomass furnace is shown in Figure 9. Two dryers having the same capacity were assembled, one equipped with a biomass furnace (SD_1) and the other without one (SD_2). Both dryers, i.e., SD_1 and SD2, were operated simultaneously to ensure the application of the same operating conditions. SD_1 was operated during off sunshine hours, while SD_2 was operated throughout the drying period. To monitor the ambient conditions, an open-sun drying experiment was also performed. In SD1, the flue gases were passed through the copper tubing embedded in the walls of the drying chamber. A control valve was used to regulate flue gas passage into the copper tubing. For experimentation, 5 mm-thick plantain slices with an initial moisture content of 66% w.b. were dried in the developed dryer (SD_1) to a final moisture content of 15%. The result shows that when the collector efficiency is 20.81% to 21.89%, the SD_1 saves 10 to 21 hours of drying time compared to the OSD. The improvement potential ranges from 0.036 to 20.6 W, while the waste exergy ratios and sustainability index range from 0.38 to 0.55 and 2.3 to 6.11, respectively. Use of the solar dryer can save between 44 - 3074 tonnes of CO_2 emissions to the atmosphere. The total energy consumption for drying ranges from 5.92 MJ to 35.47 MJ, and the specific energy consumption ranges from 4.3 Kwh/kg to 26.2 Kwh/kg. During sunshine hours, the exergy efficiency ranges from 5.6% to 95.13%.

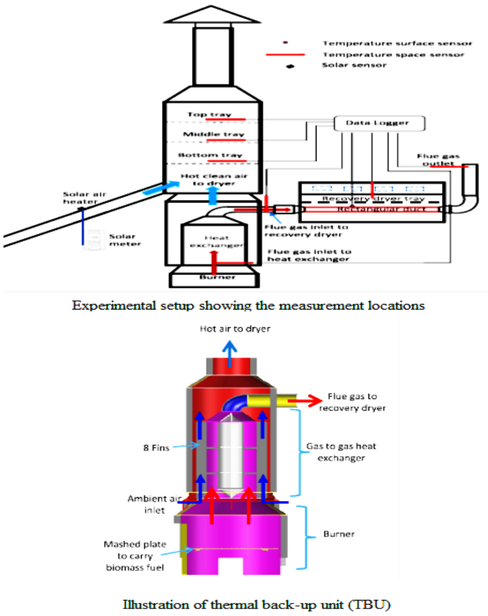


Figure 10. Hybrid solar/thermal dryer combined with supplementary recovery dryer

A Hybrid Solar/Thermal Dryer Combined with Supplementary Recovery Dryer

Tadahmun A. Yassen et al. [17] have done experimental investigation of a hybrid solar/thermal dryer Combined with supplementary recovery dryer. This present dryer system contains a mixed mode natural convection solar dryer, natural convection thermal back-up unit and recovery dryer, the schematic of the experimental setup for hybrid solar/thermal dryer Combined with supplementary recovery dryer is shown in figure 10. The waste heat of the flue gases is utilised in the supplementary dryer to enhance the performance of present hybrid dryer system. The study was conducted under two operational modes, i.e. hybrid mode (day and night) and thermal mode alone (night). As a drying material red chilli was utilised. The overall efficiency of dryer was increased from 9.9 % to 12.9% due to waste heat recovery. In the hybrid day and night drying, the enhancement of the overall efficiency was 25.84% and in the night thermal drying mode it was 29.7%. These results encourage, the use of sub dryer as thermal recovery in order to increase the system capacity.

An Integral Type Natural Convection Solar Dryer with the Provision of Biomass Heating

Jaishree Prasad and V.K. Vijay [18], developed an integral type natural convection solar dryer with the provision of biomass heating (figure 11). They evaluated the performance of the dryer for drying of ginger, turmeric and guduchi during the summer climate in Delhi. The following results were noted during the load test.

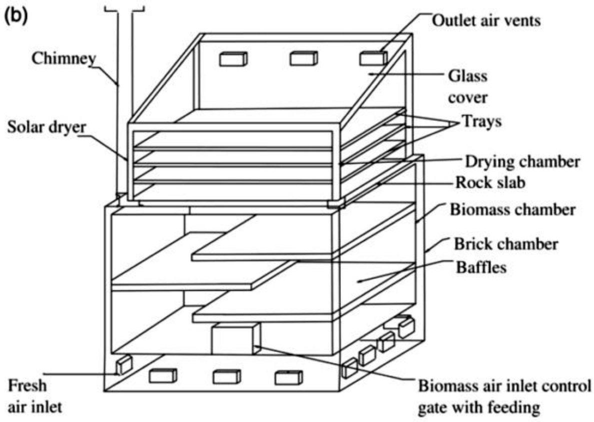


Figure 11. Schematic diagram of solar-biomass hybrid drier

Table 3. Observations noted for the natural convection solar dryer

Dried product	Measured parameters			
	Mass	Initial moisture content	Final moisture content	Drying time
Ginger	18 kg.	319.74 %	11.8 %	33 Hrs.
Turmeric	18 kg.	358.96 %	8.8 %	36 Hrs.
Guduchi	18 kg.	257.45 %	9.67 %	48 Hrs.

The drying of these products has also been studied under solar only mode, hybrid mode and open sun drying, under the same climate conditions. Results show that, the drying in hybrid mode is faster and takes 33-48 Hrs, the same dryer in solar only mode takes 72- 120 Hrs. and 192 to 288 Hrs. in open sun drying. The hybrid dryer also maintains the quality of the product against open sun drying.

A Solar Energy Drying Unit Equipped With Biomass-Fueled Air Heating

Hamdani et al. [19], developed and tested a solar energy drying unit equipped with biomass-fueled air heating. The dryer used in this study consists of biomass fueled air heaters, solar energy drying chamber, a fan and chimney as shown in figure 12. For drying fish samples having weight 26 kg and medium size, were used.

Figure 12. Hybrid drier fabrication results

During experimentation, solar energy drying was used for drying from 09:00 to 16:00 and continued further with hot air produced from biomass combustion from 16:00-06:00 with air temperature maintained at 40–50 °C. The results show that the hybrid dryer, utilising solar energy and energy from biomass, can dry the fish in only 15 hours, and when there is no sun, this system operates with biomass energy. The production cost of a hybrid dryer with a capacity of 100 kg for fish drying is $ 1870. The financial analysis for a fish production capacity of 12,000 kg/year and a selling price of $3.3 per kg gives an IRR of 18.61%, a NPV of $21.091, and a break-even point of 2.6 years.

Intelligent System Based Hybrid Solar Biomass Dryer

B.A. Anand et al. [20], designed an intelligent system-based solar biomass hybrid dryer for perishable crops and leafy vegetables. This is a mixed-mode solar biomass dryer in which the grains are dried simultaneously by both direct radiation through the transparent walls and roof of the cabinet (Figure 13).

Figure 13**.** Intelligent system based hybrid solar biomass dryer 3D view

Biomass and solar energy are used together to produce the required amount of heat to remove moisture from the perishable crops inside a drying chamber with a simulated controlled atmosphere. This dryer uses an intelligent system that is based on a microcontroller and monitors the temperature and humidity inside the dryer chamber. The controlled atmosphere inside the chamber helps to maintain the desired temperature and humidity. This unit was tested for onions, garlic, and leafy vegetables. In the present scenario, these dryers are very effective since the temperature and humidity of the drying chamber can be varied as desired. The results obtained have demonstrated the system's capabilities and efficiency.

Natural Convection Solar Biomass Integrated Drying System

A. Borah et al. [21] designed and fabricated a batch-type natural convection solar biomass Integrated Drying System (IDS) at Assam Agricultural University, Assam, India. The dryer consists of a solar collector, drying chamber, drying trays, combustion chamber, hot air generation chamber, husk feeding assembly, and chimney (Fig. 14). During experimentation, the dryer was capable of generating a continuous flow of hot air with a temperature between 55^0 C ^{and} 60^0 C. When both the heat generation system and solar insolation were at maximum, the highest temperature was noted in the IDS, around 60-65^0 C.

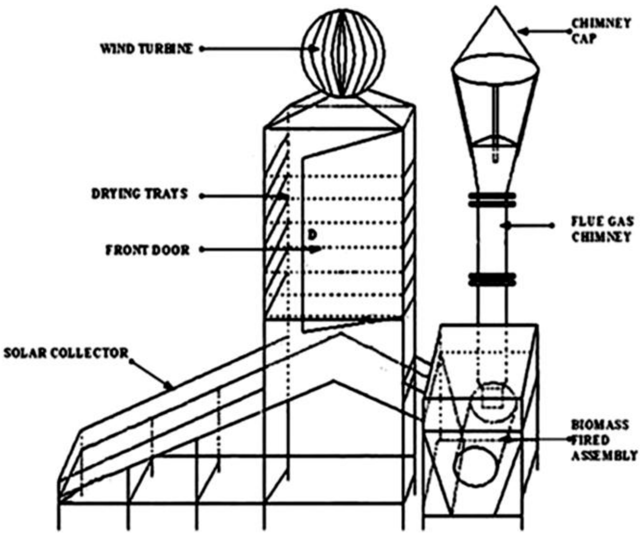


Figure 14. Schematic Diagram of Solar-Biomass Dryer

During trials, the average air velocity recorded was 0.8 m/s, and the average temperature was around 50^0 to 55^0 C. The range of relative humidity was 65 to 70%. The drying behaviour of turmeric rhizomes was noted for both OSD and IDS. The moisture content of rhizomes in IDS falls at a faster rate compared with OSD. The IDS takes 14 hours to dry sliced turmeric rhizomes from an initial moisture content of 831.09% to 6.67% (db). OSD takes 25 hours to bring down the initial moisture content to 7.58% (db). Six thin-layer drying models were tested to predict MR values. In the page and Modified Page models, the MR values found were in good agreement with the observed values. The drying conditions have a negligible effect on curcumin content. As per the hedonic scale, rhizomes dried in IDS scored better than OSD. As per quality aspect studied, IDS exhibits better performance over traditional OSD.

A Solar Biomass Hybrid Greenhouse Dryer for Drying Banana Slices

Kiburi F.G. et al. [22] evaluated the performance and economic feasibility of a solar-biomass hybrid greenhouse dryer for drying banana slices. The hybrid greenhouse dryer consists of a biomass stove, a double-duct heat exchanger, a greenhouse dryer, and drying trays, as shown in Figure 15.

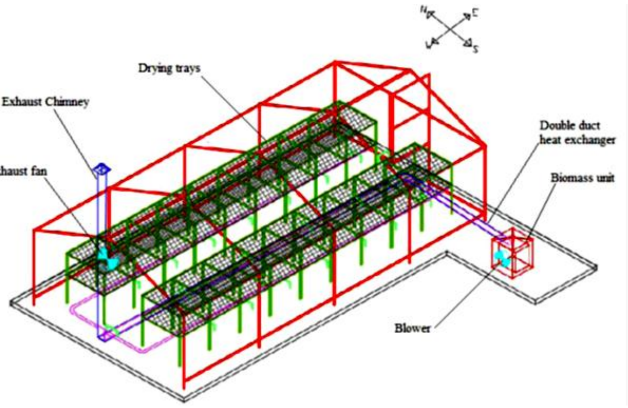


Figure 15. Schematic of the solar-biomass hybrid greenhouse dryer.

The dimensions of the greenhouse dryer were 8m x 4m x 3.6m (L x W x H), and it was glazed with UV-stabilised polythene film having a thickness of 0.2 mm. The evaluation of the dryer's performance was done on the basis of drying air properties, drying rates, energy efficiency, energy utilisation, and exergy efficiency. The drying results obtained were as below:

Table 4. Operational results for drying banana slices in three different modes

Measured parameter	Mode of drying		
	Solar mode	**Biomass mode**	**Solar Biomass mode**
Temperature difference between inside and ambient	12.96 °C	8.88 °C	13.21 °C
Relative humidity difference between inside and ambient	8.76 %	24.26 %	27.91 %
Mean drying rate (g/gdm/hour)	0.28	0.21	0.23
Average energy utilization ratio	35.58	40.60	33.46
Exergy efficiency	64.60	59.37	66.50

The expected life of the dryer is 4 years and the payback period of the dryer was found less than one year.

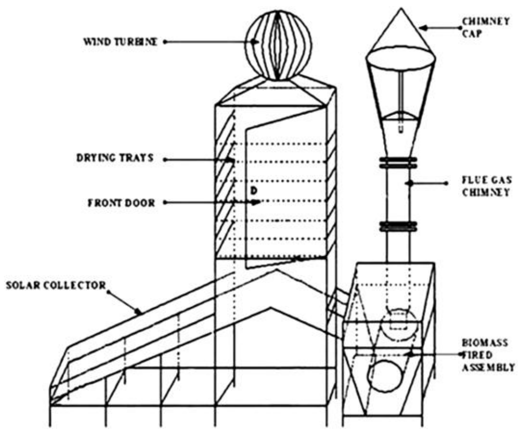


Figure 16. Schematic diagram of integrated drying system

A Solar Biomass-Fired Integrated Drying System with a 100 Kg/Batch Capacity

Borah et al. [23] designed and developed a solar biomass-fired integrated drying system (IDS) for drying turmeric rhizomes and ginger with a 100 kg/batch capacity. A compound parabolic solar collector attached to bio-waste-fired combustion and connected with a drying chamber. The drying cabinet has six trays and a wind turbine at the top to create the required draught (Fig. 16). Prior to drying, Ginger rhizomes were washed and sliced to 3–4 mm in thickness and 50–70 mm in length. Similarly, turmeric rhizomes were washed and boiled in hot water for 1.5 hours before being sliced to the same size as those of ginger. For drying sliced ginger and turmeric, thin-layer drying experiments were carried out. For comparison, an electrical oven (EO), a fluidized bed dryer (FBD), and open-sun drying were used. In comparison to ginger drying, 21% more effective moisture diffusivity was noted for turmeric drying. Minimum Specific Energy Consumption (SE) occurs in IDS, which is 14 times less than FBD and 30 times less than OSD. The IDS showed 36.33% overall energy utilisation efficiency, considering the latent heat of vaporisation and total heat available in the plenum chamber. For the developed IDS, high entrepreneurial possibilities were reflected with a break-even of 17.70% for the 10-year run-up.

An Automated Solar Biomass Hybrid Dryer

George Obeng-Akrofi et al. [24] have used CFD to simulate the drying process of an automated solar biomass hybrid dryer located at Ejura. The five-ton SBHD consists of three main parts: the solar photovoltaic system, the drying chamber, and the backup heat generation system (Figure 17).

Figure 17**.** Five tonne capacity dryer located in Ejura

There are four levels, with 36 trays on each level, inside the drying chamber. For investigating the temperature distribution inside the dryer, CFD simulations were set up with the software Star CCM+. Experimental data on the temperature distribution in the dryer were compared with the CFD-predicted temperature distribution. For levels 1 And 2 within the dryer, the simulated results were 5 to 15 K higher than the experimental data. This happens due to the cold air at the bottom of the dryer and the absence of the effect of the fan in the dryer during the simulation process. For levels 3 and 4, the simulation results fit perfectly and have a temperature deviation of only 5 K. Overall, the predicted simulation agrees with the experimental data, and it is suggested to aid the controlled introduction of hot air at the lower levels of shelves. The main objective of this work was to develop a CFD model for the solar hybrid dryer.

An Innovative Solar-Biomass Hybrid Dryer for Rubber Sheet Drying

Sonthawi Sonthikun et al. [25]. Designed an innovative solar biomass hybrid dryer and validated the CFD results using experimental analysis. The SBHD was designed and constructed for natural rubber sheet drying, and it consists of a biomass furnace and heat exchanger, as shown in figure 18.

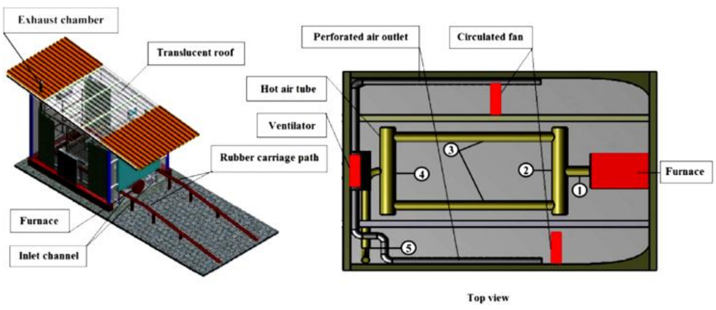


Figure 18. Solar-biomass hybrid dryer for rubber sheet drying.

During the day, solar energy was directly used for heating the inside air, and during off-peak hours, biomass was burned to maintain the inside temperature. Along with CFD simulation modelling, experiments were carried out to validate the temperature distribution and air flow phenomena inside the solar biomass hybrid dryer. Fluent ANSYS software was used to investigate the CFD simulation. During experimentation, the temperature distribution was recorded at three planes, which gave a reading very close to the average drying chamber temperature. The coefficient of determination (0.96e0.99) and root mean square of percent error (2.27e5.68%) were calculated, and it is concluded that the predicted values are in harmony with the observed values. This present CFD simulation model will be helpful in designing a solar biomass hybrid dryer for a given capacity. The MC of rubber sheet is reduced from 34.26% (db) to 3% (db) in 36 hours and remains at 0.34% after 48 hours. The design of this SBHD is economical and recommendable to smallholders.

4.19. CFD supported performance analysis of an innovative biomass dryer for different tray designs

Sumeet Anand et al. [26] have done a CFD-supported performance analysis of an innovative biomass dryer. This work discusses the flow characteristics and heat transfer of a novel biomass dryer for different variations in tray configurations (Figure 19).

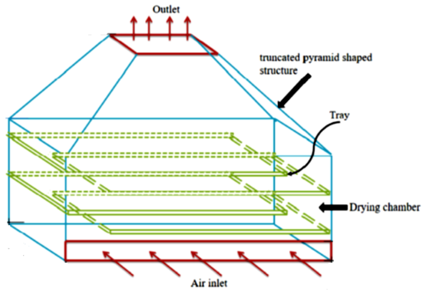


Figure 19. Computational domain with solid trays attached to the drying chamber walls

Different tray designs proposed in this work have been examined using the flow analysis tool Fluent-17. The drying air enters the chamber at the bottom of the side wall and exits at the top. The side walls and bottom walls are subjected to a constant temperature boundary condition. Fluent-17 has been used for solving the governing equations of mass, energy, momentum, and turbulence. The effect of tray arrangement (tray number, tray length, and hole arrangement) on the tray surface has been used to account for heat transfer and pressure drop. Results show that heat transfer as well as pressure drop increase with an increase in tray number; hence, the optimum tray number is fixed on the basis of the highest enhancement factor. Within six different tray arrangements, the alternative packed side and rear front wall arrangement of the tray gives the best thermofluid performance. On the basis of hole arrangements on the tray surface, the staggered arrangement results in higher heat transfer without any pressure drop. For different tray numbers, tray lengths, and inline and staggered hole arrangements, correlations have been established to forecast the enhancement factor. With the increase in tray number from 3 to 9, the enhancement factor increases to 35% and 57% at Re = 3235 and Re = 4529, respectively, compared to the biomass.

Validation of the Experimental Results, By Mathematical Models in a Solar Biomass Hybrid

Dhanushkodi et al. [27] investigated the drying behaviour of cashew nuts experimentally in a solar biomass hybrid dryer using mathematical models. The solar biomass dryer, shown in figure 20, consists of a drying chamber, a solar collector, a biomass back-up heater, and a blower.

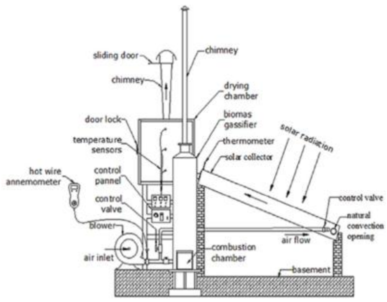


Figure 20. Schematic and pictorial view of solar biomass hybrid dryer

The experimental data obtained were fitted to the different empirical drying models. The drying models performances were compared on the basis of correlation coefficient (R^2), reduced chi-Square (**2**) between the experimental moisture ratios, and Root Mean Square Error (RMSE). The two terms and Midilli models exhibited the best fit in solar drying. For describing the thin layer drying behaviour of cashew for biomass drying and hybrid drying, the Page model was found to be the best model. The present biomass hybrid dryer can be redesigned based on the mathematical model to enhance drying performance.

3. Results and Discussion

Some of the results of experiments carried out by different researchers have been tabulated below in terms of special design features, dried product, and time taken in SBHD compared with OSD.

Table 5. Noticeable findings of the experimentations carried out by different researchers

Researcher	Special design features	Product dried	Time taken in OSD	Time taken with SBHD	Performance Remarks
M. K. Mishra et al.	SBHD with an automatically controlled gasifier stove	Chili (16 kg)	48 hours	20 hours	Overall efficiency of dryer was estimated around 4.29%.
M. Yahya	Solar assisted heat pump dryer integrated with biomass furnace	Red chillies (22 Kg)	62 hours	11 hours	Drying rate about 1.57 kg/kWh and thermal efficiency about 9.03 %.
S.C. Bhattacharya et al.	Hybrid solar biomass energy powered dryer	banana (16 kg) and chilli (16 kg)	66 hours 48 hours	18 hours 22 hours	- -
M.C. Ndukwu et al.	Hybrid solar biomass dryer integrated with copper tubing as heat exchanger	Plantain slices	-	saves 10 to 21 Hrs compared to OSD	
Tadahmun A. Yassen et al.	A hybrid solar/thermal dryer Combined with supplementary recovery dryer	Red chilli	-	-	The enhancement of the overall efficiency was 25.84% and in the night thermal drying mode it was 29.7%.
Jaishree Prasad and V.K. Vijay	Integral type natural convection solar dryer with the provision of biomass heating	Ginger, Turmeric, and Guduchi (18 Kg. batch for each)	192 to 288 Hrs.	33-48 Hrs	-
Hamdani et al	Drying unit equipped with biomass-fueled air heating.	Fish (26 Kgs.)	-	15 hrs	-
A. Borah et al.	Natural convection solar biomass integrated drying system	Turmeric rhizomes	25 Hrs	14 Hrs	36.33% overall energy utilization
Kiburi F.G. et al.	Solar biomass hybrid greenhouse dryer	Banana slices	-	-	Overall efficiency 27.91 %

From the above comparison in Table 5, it can be observed that the drying time mostly depends on the climatic conditions and initial moisture content of the product to be dried. The maximum overall thermal efficiency of 36.33% is possible with the natural convection solar biomass integrated drying system. The thermal efficiency can be increased by optimising the use of heat energy in biomass-generated flue gases. A lot of the heat energy in flue gases goes to waste, which can be used to pre-heat the incoming air in the drying cabinet. The solar and biomass dryers in combination have the capability to increase productivity and are also economically viable for small and medium-scale agro-processing industries in emerging countries.

Table 6. Outcome for the software, mathematical modelling and optimization analysis carried out by different researchers

Researcher	Special design features	Performance Remarks
A. Madhlopa and G. Ngwalo	Natural convection solar dryer with integrated collector-storage and biomass backup heater	Optimization of the system and transparent insulation of the exterior surface of the solar chimney was suggested as improvement to avoid reverse thermosiphoning.
Ndirangu, S. N et al.	A gable roof greenhouse solar-biomass dryer	The experimentation was carried out under three modes of oration i.e. natural ventilation, forced convection and solar biomass hybrid mode. No temperature difference was found between lower and upper beds under the three modes.
V.P. Sethi and Mankaran Dhimanto	Solar cum biomass hybrid greenhouse crop dryer	Vertical clearance between two successive trays is optimized
M.C. Ndukwu et al.	Low-cost hybrid solar drying system	Presented the drying kinetics, heat transfer coefficient and thin layer models for the dried product and thermal models are established to forecast the solar radiation availability and HGCD chamber air temperature
A. Bosomtwe et al.	5.0-MT Solar Biomass Hybrid Dryer containing a solar tent and a furnace	SBHD is effective for both drying and disinfestation of grain.
George Obeng-Akrofi et al.	An automated solar biomass hybrid dryer	The main objective of this work was to develop a CFD model for the solar hybrid dryer. Used CFD to simulate the drying process of an automated solar biomass hybrid dryer
Sonthawi Sonthikun et al.	An innovative Solar-biomass hybrid dryer for rubber sheet drying	Along with CFD simulation modelling experimentation were carried out to validate the temperature distribution and air flow phenomenon inside solar biomass hybrid dryer. FLUENT ANSYS software was used to investigate the CFD simulation.
Sumeet Anand et al.	An innovative biomass dryer for different tray designs	Different tray designs proposed in this work has been examined by using flow analysis tool Fluent-17.
S. Dhanushkodi et al.	Solar biomass hybrid dryer	The drying models performances were compared on the basis of correlation coefficient (R^2), and Reduced Chi-Square (χ^2) between the experimental moisture ratios and root mean square error (RMSE). The two terms and Midilli models exhibited the best fit in solar drying.

The findings of other researchers who carried out their experimentation with their novel designs and validated the results with the help of software like CFD and FLUENT ANSYS have been summarised in the above table 6. Some of the researchers optimised the results for varying tray arrangements, while others presented the drying kinetics with the help of mathematical models.

4. Conclusions

The use of solar biomass hybrid dryers for agricultural and marine products has a large potential from a technical and energy-saving point of view. Several types of solar biomass hybrid dryers have been designed and developed in numerous parts of the world, yielding varying grades of technical performance. This review gives validation for the use of solar biomass hybrid dryers as an inexpensive and cost-effective alternative method to overcome the limitations of traditional sun drying, especially in low-income countries. Numerous types or designs of solar biomass hybrid dryers can be fabricated according to the financial availability, locality, and obligations of the materials to be dried. With the help of SBHD, we can continuously dry the products, irrespective of the climate conditions.

The availability of biomass is abundant, and we can use agricultural waste at a very reasonable cost. The maximum thermal efficiency noted is only 36.33%. The SBHD can be made more energy efficient by ensuring the optimum use of heat energy generated by the combustion of biomass. Solar-assisted biomass hybrid dryers can play a vital role in the preservation of agricultural produce in developing countries. The solar and biomass combination dryer has the potential to increase productivity and is also economically worthwhile for small and medium-scale agro-processing units in developing states.

List of Abbreviations:
SBHD = Solar Biomass Hybrid Dryer
CFD = Computational Fluid Dynamics
OSD = Open Sun Drying
HSD = Hybrid solar dryers
w. b. = Wet Basis
db = Dry Basis
MBE = Mean Bias Error
RMSE = Root Mean-Square Error
SD = Solar Drying
IDS = Integrated Drying System
FBD = Fluidized Bed Dryer
R^2 = The Coefficient of Determination
HGCD = Hybrid Greenhouse Crop Dryer
TDK = Thermally Damaged Kernels
RS = Right Section
LS = Left Section
MS = Middle Section
IRR = Internal rate of Return
NPV = Net Present Value
UV= Ultra Violet
EO = Electrical Oven
STAR-CCM+ **=** is a commercial Computational Fluid Dynamics (CFD) based simulation software
MC = Moisture Content

Declarations
Availability of Data and Material: "This study was a re-analysis of existing data, which is openly available at locations cited in the reference section."

Competing Interests: the authors declare that we do not have any competing interests."
Funding: No funding was obtained for this study.

Authors' Contributions: The manuscript entitled "A Review on Solar Biomass Hybrid Dryers" has been read and approved here by all the authors. Our contribution to the preparation and publication of the manuscript is as mentioned below. Corresponding Author 1. has made a substantial contribution to the concept or design of the article or the acquisition, analysis, or interpretation of data for the article; Author 2. has drafted the article or revised it critically for important intellectual content; AND Author 3. has approved the version to be published.

Acknowledgements: We thank our colleagues from GF's Godavari College of Engineering, Jalgaon, who provided insight and expertise that greatly assisted the research. We thank Dr. V. G. Arajpure for his assistance and suggestions that greatly improved the manuscript. We would also like to show our gratitude to Kavayitri Bahinabai Chaudhari, North Maharashtra University, Jalgaon, for sharing their pearls of wisdom with us during the course of this research. Also, we are immensely grateful to the members of the RRC from KBCNMU Jalgaon for their comments on an earlier version of the manuscript, although any errors are our own and should not blemish the reputations of these esteemed persons.

5. References

1. Chandramohan VP, Talukdar P., "Deformation of potato during convective drying", Appl Mech Mater 2014; 592–594:2728–32. https://doi.org/10.4028/www.cientific.net/AMM.592-594.2728.
2. Mennouche D, Bouchekima B, Boubekri A, Boughali S, Bouguettaia H, Bechki D., "Valorization of rehydrated Deglet-Nour dates by an experimental investigation of solar drying processing method", Energy Convers Manag 2014; 84:481–7. https://doi.org/10.1016/j.egypro.2014.06.109.
3. Anderson JO, Westerlund L., "Improved energy efficiency in saw mill drying system", Appl Energy 2014; 113:891–901. https://doi.org/10.1016/j.apenergy.2013.08.041.
4. Hisham Elhage, Amal Herez, Mohamad Ramadan, Hasan Bazzi, Mahmoud Khaled "An investigation on solar drying: A review with economic and environmental assessment" PII: S0360-5442(18)31043-0, DOI: 10.1016/j.energy.2018.05.197, Reference: EGY 13032
5. Okoroigwe E. C., Eke M. N. and Ugwu H. U., "Design and evaluation of combined solar and biomass dryer for small and medium enterprises for developing countries" Vol. 8(25), pp. 1341-1349, 9 July, 2013, DOI: 10.5897/IJPS2013.3937, ISSN 1992 - 1950 © 2013 Academic Journals
6. A. Fudholi , K. Sopian, M.H. Ruslan, M.A. Alghoul, M.Y. Sulaiman, "Review of solar dryers for agricultural and marine products", Renewable and Sustainable Energy Reviews 14 (2010) 1–30. www.elsevier.com/locate/rser.
7. M. K. Mishra1, K. R. Shrestha1, V. Sagar , R. K. Amatya1, "Performance of hybrid

solar-biomass dryer", Nep J Environ Sci (2017), 5, 61-69, ISSN 2350-8647 (Print) 2542-2901 (Online).

8. M. Yahya, "Design and Performance Evaluation of a Solar Assisted Heat Pump Dryer Integrated with Biomass Furnace for Red Chilli", International Journal of Photoenergy, Volume 2016, Article ID 8763947, 14 pages, http://dx.doi.org/10.1155/2016/8763947.
9. A. Madhlopa , G. Ngwalo, "Solar dryer with thermal storage and biomass-backup heater", Solar Energy 81 (2007) 449–462, www.elsevier.com/locate/solener.
10. Ndirangu, S. N., E. K. Ronoh, C. L. Kanali, U. N. Mutwiwa, G. M. Kituu, " Design and performance evaluation of a solar-biomass greenhouse dryer for drying of selected crops in western Kenya", Vol. 22, No. 3, September, 2020, AgricEngInt: CIGR Journal Open access at http://www.cigrjournal.org.
11. S.C. Bhattacharya, Tanit Ruangrungchaikul and H.L. Pham, "Design and Performance of A Hybrid Solar/Biomass Energy Powered Dryer for Fruits and Vegetables", Worm Renewable Energy Congress VI (WREC2000) © 2000 Elsevier Science Ltd.
12. V.P. Sethi, Mankaran Dhiman, "Design, space optimization and modelling of solar-cum-biomass hybrid greenhouse crop dryer using flue gas heat transfer pipe network", Solar Energy 206 (2020) 120–135, https://doi.org/10.1016/j.solener.2020.06.006
13. M.C. Ndukwu, E.O. Diemuodeke, F.I. Abam, U.C. Abada, Nnanna Eke-emezie, M. Simo-Tagne, " Development and modelling of heat and mass transfer analysis of a low-cost solar dryer integrated with biomass heater: Application for West African Region", Scientific African 10 (2020) e00615, http://creativecommons.org/licenses/by-nc-nd/4.0/
14. A. Bosomtwe, J.K. Danso, E.A. Osekre, G.P. Opit, G. Mbata, P. Armstrong, F.H. Arthur, J. Campbell, N. Manu, S.G. McNeill, J.O. Akowuah, "Effectiveness of the solar biomass hybrid dryer for drying and disinfestation of maize", Journal of Stored Products Research 83 (2019) 66e72, https://doi.org/10.1016/j.jspr.2019.05.011
15. Joseph O. Akowuah, Dirk Maier, George Opit, Sam McNeill, Paul Amstrong, Carlos Campabadal, Kingsly Ambrose, George Obeng-Akrofi, "Drying Temperature Effect on Kernel Damage and Viability of Maize Dried in a Solar Biomass Hybrid Dryer", Open Journal of Applied Sciences, 2018, 8, 506-517, ISSN Online: 2165-3925, ISSN Print: 2165-3917, http://www.scirp.org/journal/ojapps.
16. M.C. Ndukwu, M. Simo-Tagne , F.I. Abam , O.S. Onwuka , S. Prince , L. Bennamoun , "Exergetic sustainability and economic analysis of hybrid solar-biomass dryer integrated with copper tubing as heat exchanger", Heliyon 6 (2020) e03401, https://doi.org/10.1016/j.heliyon.2020.e03401
17. Tadahmun A. Yassen, Hussain H., Al-Kayiem, "Experimental investigation and evaluation of hybrid solar/thermal dryer combined with supplementary recovery dryer", Solar Energy 134 (2016) 284–293, http://dx.doi.org/10.1016/j.solener.2016.05.011
18. Jaishree Prasad, V.K. Vijay, "Experimental studies on drying of Zingiber officinale, Curcuma longa l. and Tinospora cordifolia in solar-biomass hybrid drier", Renewable Energy 30 (2005) 2097–2109, doi:10.1016/j.renene.2005.02.007, www.elsevier.com/locate/renene.
19. Hamdani, T.A. Rizal and Zulfri Muhammad, "Fabrication and Testing of Hybrid Solar-Biomass Dryer for Drying Fish", Case Studies in Thermal Engineering, https://doi.org/10.1016/j.csite.2018.06.008.
20. B.A. Anand, P. Manjunath Babu and B.A. Sunil Raj, "Intelligent System Based Solar Biomass Hybrid Dryer for Perishable Crops and Leafy Vegetables", Int. J. Curr. Microbiol. App. Sci (2018) 7(10): 1701-1707, ISSN: 2319-7706 Volume 7 Number 10 (2018).
21. A. Borah, L. N. Sethi, S. Sarkar And K. Hazarika, "Drying Kinetics Of Sliced Turmeric (Curcuma Longa L.) In A Solar-Biomass Integrated Drying System", Journal of Food Processing and Preservation 00 (2016) 00–00 VC 2016 Wiley Periodicals, Inc.
22. Kiburi FG, Kanali CL, Kituu GM, Ajwang PO, Ronoh EK, "Performance Evaluation and Economic Feasibility of a Solar-Biomass Hybrid Greenhouse Dryer for Drying Banana Slices", Renewable Energy Focus (2020), doi: https://doi.org/10.1016/j.ref.2020.06.009.
23. A. Borah, L. N. Sethi, S. Sarkar and K. Hazarika, "Energy Utilization Efficiency and Entrepreneurial Potential of a solar biomass Integrated Drying System", Journal of Agricultural Engineering Vol. 54 (2): April-June, 2017, http://www.isae.in / journal_jae.aspx
24. George Obeng-Akrofi, Joseph Oppong Akowuah, Gifty Opoku-Agyeman, Isaac

Nkrumah, Michael K. E. Donkor, Reuben Y. Tamakloe, Francis K. Ampong, Maike Waldhoff, Tobias Klaus, Alexander Olenberg, Eugeny Kenig and Stefan Krauter, "An automated solar biomass hybrid dryer in rural communities in Ghana", SWC 2017 / SHC 2017 / ISES Conference Proceedings (2017), http://proceedings.ises.org.

25. Sonthawi Sonthikun , Phaochinnawat Chairat, Kitti Fardsin, Pairoj Kirirat , Anil Kumar and Perapong Tekasakul, "Computational fluid dynamic analysis of innovative design of solar biomass hybrid dryer: An experimental validation", Renewable Energy 92 (2016) 185e191, http://dx.doi.org/10.1016/j.renene.2016.01.095.

26. Anand S, Mishra DP, Sarangi SK, "CFD supported performance analysis of an innovative biomass dryer", Renewable Energy (2020), doi: https://doi.org/10.1016/j.renene.2020.06.039.

27. S. Dhanushkodi, Vincent H. Wilson, K. Sudhakar, "Mathematical modeling of drying behavior of cashew in a solar biomass hybrid dryer", Resource-Efficient Technologies (2016), doi: 10.1016/j.reffit.2016.12.002, www.elsevier.com/locate/reffit.