

**REVIEW****Industrial and Small-Scale Biomass Dryers: An Overview****P. Murugan<sup>1</sup>, S. Dhanushkodi<sup>2,\*</sup>, K. Sudhakar<sup>3,4,\*</sup> and Vincent H. Wilson<sup>5</sup>**

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**ABSTRACT**

The quality of the drying process depends mainly on the efficient use of thermal energy. Sustainable systems based on solar energy takes a leading role in the drying of agro-products because of low operating cost. However, they are limited in use during off-sun periods. Biomass dryer is one of the simplest ways of drying because of its potential to dry products regardless of time and climate conditions. The other benefit is that crop residues could be used as fuel in these systems. However, the major limitation of the dryer is unequal drying because of poor airflow distribution in the drying medium, which can be improved by integrating some design changes in the dryer. This review analyses the two types of biomass dryers: industrial biomass dryers and small biomass dryers for food product, along with their efficiency. Further, studies on technical, sustainability and economic aspects are expected to provide a greater understanding of biomass drying.

**KEYWORDS**

Biomass dryer; sustainable energy; biomass; direct; indirect; drying time

**1 Introduction**

Thermal drying is a common method of moisture removal applied in industrial and agricultural processes. Drying is carried out for different purposes: to simplify and reduce the cost of biomass transportations, to increase the material strength, and to ensure easier processing [1]. Drying is an essential technological activity to improve the quality of the product. Drying requires high energy usage, which accounts for approximately 15% of electricity consumption. It is, therefore, very crucial to identify the optimum design and use of the drying process. Biomass, in particular fuelwood, is a predominant form of renewable energy in rural areas. The term biomass sources refer to forest resources, agro-residues, Wastes, and municipal organic sewage, solid waste such as poultry and livestock dung [2]. Biomass moisture content is exceptionally high, somewhere between 50 and 63%, based on the weather, climate, and nature of source. It is, therefore, necessary to dry the biomass to minimize the moisture



content to an acceptable value of approximately 12–15% for further use [3]. The characteristic calorific value of solid biomass is around 15–22 MJ/kg; various drying processes are used to dry different products. The most common installations are those where convection drying with hot air or a mixture of air and exhaust gases as a drying medium takes place [4]. One of the cheapest alternative sources of heat, is the use of biomass waste from agricultural farms and agro-processing agro-industry. It is not only environmentally friendly but also offer benefits both in urban and rural areas for commercial purposes as they are much simpler compared with several other forms of dryers.

The objective of the present review is to discuss and compare the different biomass dryers. The various design and new development of biomass dryers are discussed.

## 2 Background of Dryers

### 2.1 Classification of the Dryer

The essential requirements of the dryer are the heat supply with hot air or steam, the removal of evaporated water from the material and the transfer of the wet surface to the drying medium through agitation or other means. Therefore, selecting an appropriate drying method is vital in the drying process of these perishable commodities [5]. *Tab. 1* provides the various criterion for the classification of dryers.

**Table 1:** Classification of dryers [4,5]

Criterion	Types
Operation mode	Batch and Intermittent or continuous
Heat input	Convection, conduction, radiation
Medium of drying	Air, flue gases, superheated steam,
Available fuel	Solar, biomass, and electric
Mode of heating	Direct and indirect dryer

### 2.2 Comparison of Various Dryers

As illustrated in *Tab. 2*, the solar drying technique has several advantages in meeting the drying needs of small-scale farmers due to its lower running cost. For solar dryers, however, the objective is to ensure continuous drying, regardless of times of low insolation, like cloudy or rainy days and night-time. Optimal use of biomass dryer means a decrease in drying time and continuous operation compared to solar dryers [6]. Every method has its advantages and disadvantages.

### 2.3 Selection Criteria for Industrial Dryers

The most significant concern in selecting the dryers is the scale of production and the subsequent use of dried biomass. There is a lack of a systematic framework for selecting the appropriate drying method for different materials. Similarly, the lack of proper data on the dried product's physical and chemical characteristics complicates dryer selection. *Fig. 1* describes the characteristic features to be considered for dryer selection. Choosing the right dryer depends on a variety of factors, such as the characteristics of the drying material, heat source, capital cost, operating and maintenance requirements, environmental pollution, energy consumption, drying temperature, available room and safety issues.

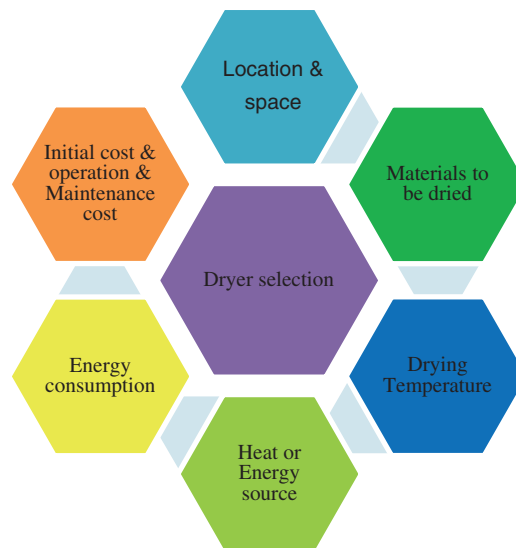
Besides, the drier selected should be able to meet the following conditions [7,8]

- **Continuous operation:** Smooth running of the dryer assembly line so that no waste of fuel occurs. It is essential to ensure nearly consistent drying with less drying time.

- **Easy to load/unload:** The unloading and loading of biomass should be simple. A single individual must be in a position to operate the dryer.
- **Easy manoeuvrability:** Movement and handling of the equipment, dried biomass, and storage should be more accessible without difficulty.
- **Uniform drying:** Uniform drying is an essential aspect of practical usage and marketability. Therefore, the biomass must be dried uniformly by the dryer without any issues of excess temperature (>120°C), overheating, and burning of biomass eventually.
- **Minimal external power use:** The design should operate with a minimum external power source.

**Table 2:** Comparative study of various dryers [6,7]

S. No.	Parameters	Biomass dryer	Solar dryer	Electric dryer
1	Input energy	Wood/agricultural waste	Sun heat	Electricity
2	Cost of the fuel	Low cost	No cost	Expensive
3	Energy production time	Always	Sunny days	Minimum hours each day
4	Dryer temp	Up to 100°C	Based on sun lights	Same as biomass
5	Capacities	Maximum	Minimum	Low
6	Cost of the dryer	Low cost	High cost	Moderate
7	Working time	All days	Sunny days only	Only based on the supply of power
8	Performance	31–43%	15–28%	N/A



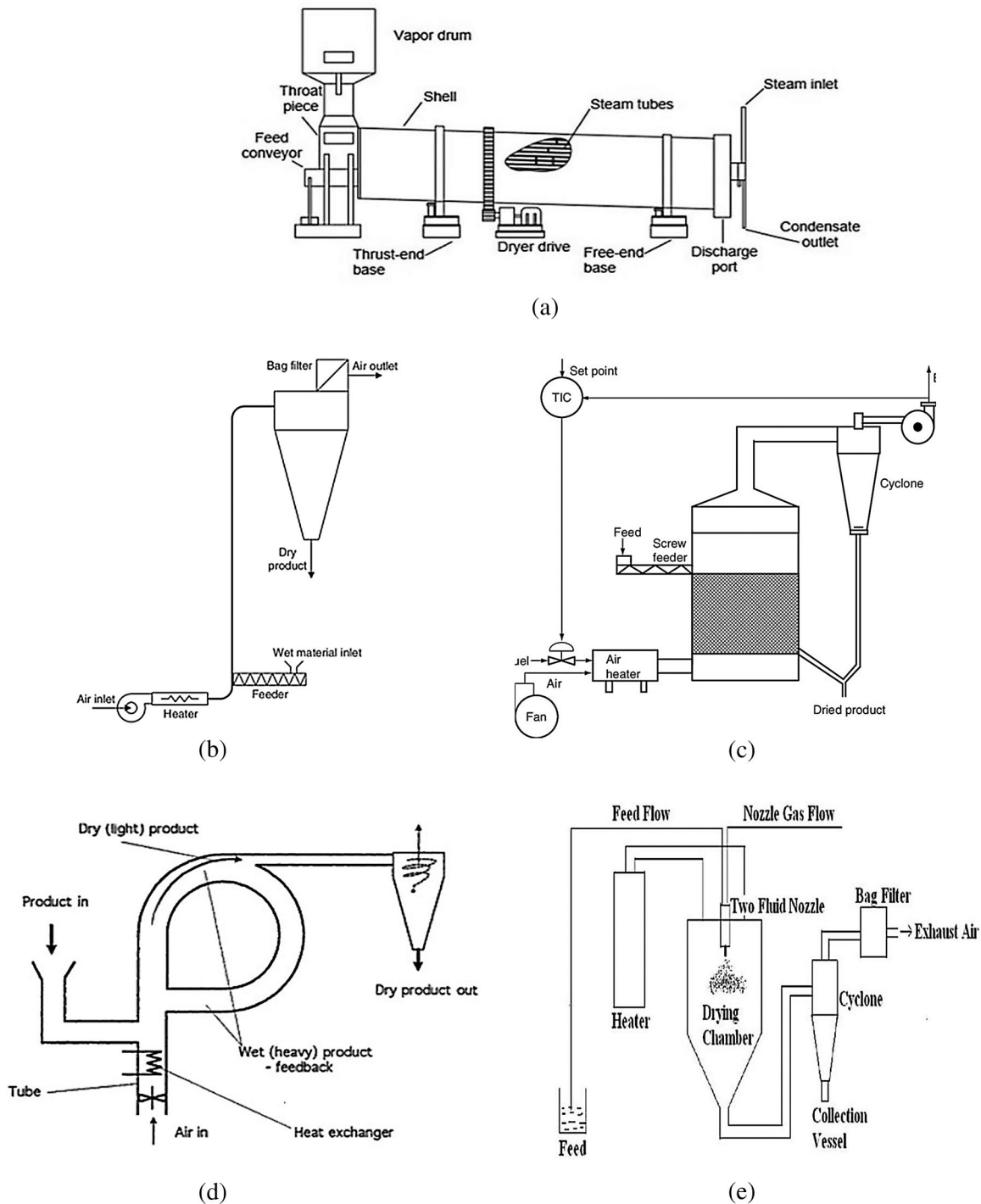
**Figure 1:** Factors to be considered for dryer selection

### 3 Overview of Industrial Processes for Biomass Drying

#### 3.1 Description of Industrial Biomass Dryers

Drying biomass of higher density and moisture are perfectly suitable for further use in combustion processes like boilers, gasifiers, and pyrolysis. The most commonly used biomass dryer technologies are

a) Rotary drum (b), Flash/pneumatic (c), Fluidized bed, (d), Ring, and (e), Spray, and their diagrams are shown in Fig. 2. These systems are not appropriate for drying low-density and low initial moisture content products. Typical information obtained for various dryers is presented in Tab. 3 and other vital considerations [8].



**Figure 2:** Schematic diagram of biomass dryer [8–10] (a) Rotary drum (b) Flash (c) Fluidized bed (d) Ring (e) Spray

**Table 3: Summary of different type of biomass dryers [10–14]**

S. No.	Type of dryer	Rotary drum	Flash/Pneumatic	Ring	Cascade/Fluidized bed	Spray
1	Applicable Industries	1. Food company 2. Chemical company 3. Medicine	1. Food company 2. Mineral company 3. Chemical factory	1. Food company 2. Grains 3. Distilleries	1. Food company 2. Mineral company 3. Chemical industry 4. Polymer	1. Food company 2. Medicine
2	Design & characteristics	It has a cylinder rotating drum for the contact of biomass material with hot gases, Large capacity; feed size flexibility	The Solid is mixed with hot air. Less residence time and particle size; ease of control;	Manifold for recirculation Intimate contact with air & rapid drying Adjustable splitter blades are used Low exhaust temperature Instantaneous drying	Hot air is passed through distributor plate—gas flow with high velocity. Less particle size;	Hot air is supplied via the top of the dryer. Drying in two steps. Drying is using liquid droplets. Droplet/gas mixing occurs. Atomizer or spray nozzle is used. The final product collects at the bottom of the dryer
3	Advantages	1. Simple operation 2. Less maintenance 3. More capacity 4. Ability to handle wide feeds	Rapid drying Fewer fire hazards Compact than rotary dryers low VOCs emissions Most biomass can be used	1. Less time required 2. Simple design & reliable 3. Smallest footprint 4. Improved form of Flash dryer	Can dry more volume of product than flash Smaller footprint than rotary	1. Gentle drying 2. High production rate 3. Superior product quality 4. High thermal efficiency
4	Disadvantages	1. More energy consumption 2. Moisture control is difficult 3. High cost of fuel & emissions 4. Large footprint	Particle size must be smaller Heat recovery is difficult Lower fire risk than rotary high installation cost	High installation cost High heating requirements Require small particle size. .	Skilled labor is needed Corrosion & erosion issues High O&M cost	More area is needed.
5	Heating source	Flue gas/hot air/steam	Hot air	Hot air	Flue gas/hot air/steam	Hot air
6	Drying efficiency	85%	50–75%	N/A	40–80%	50%
7	Product temperature	80–110	60–120	N/A	60–100	60–130
8	Evaporation capacity kg/m <sup>2</sup> -h	5–30	10–100	N/A	30–90	1–30
9	Residence time	10–30 s	2–20 s	N/A	2–20 min	10–60 s
10	Energy consumption (M.J./Kg)	4.6–9.2	4.5–9.0	N/A	4.0–6.0	4.5–11.5

### 3.2 Rotary Drum Dryer

Drum dryer is quite commonly used for the drying of biomass. It consists of a large, slightly inclined cylindrical drum 2 to 3 m in diameter and 15–20 m in length, which rotates around 1 to 10 rpm around its axis [9]. The drum is equipped with a sequence of external flights designed to raise, disperse the substance; the hot gas is supplied directly to the drum, which is mechanically turned by an electric system. The energy loss to the product and the evaporation of the water vapour decreases the temperature of the gas. The speed of rotation, the drum inclination, the flow rate, and temperature of the gas influence the removal of moisture from the substance.

### 3.3 Pneumatic (Flash) Dryer

The solid is injected into a high-speed hot air stream of the order of 25 m/s with the support of a screw conveyor. The turbulent hot gasses act as a carrier for the mass transport of humidity from the material to the gases. Finer particles flow through a lengthy metal tube ( $L > 100$  m;  $d = 0.3$  to  $0.5$  m). The dried product is separated from the air stream utilizing cyclones and bag filters. Increased drying temperatures will be used for several materials since the “flashing” of the water vapors instantly starts to cool the drying gas without significantly impacting the temperature of the product. The product is transferred from the bottom of the collection equipment to the silo. The drying load of high-capacity modern dryers should be at least 20 tonnes of evaporated water per hour [9].

### 3.4 Ring Dryer

The concept is the same as a flash dryer [9]. The drying material is uniformly spread and transferred in a hot stream of air. The centrifugal classifier is used for restricted internal recirculation of semi-dried solids, thereby extending the retention time of larger particles in the dryer. Finer particles dry more quickly and leave the dryer along with the exhaust air. The wetter (heavier) particles through the centrifugal motion, continue to follow the manifold more closely than the lighter fractions that are borne along with the air stream. The blades are adjusted to push smaller, dried particles out of the dryer for storage, while heavier particles are recycled through the ring duct for further drying.

### 3.5 Fluidized-Bed Dryer

Fluidized bed dryers are the cheapest and most efficient drying methods for drying wet that don't stick or clump. Warm air flows through the bed through a corrugated distributing plate; the velocity is high enough to lift the particles in a fluidized state. Bubbles grow and fall within the material surface, along with the moving particles. The time of residence of the dryer material is 30–120 sec for the removal of the surface mixture [10]. Fluidized beds allow for more efficient mass and heat transfer, proper solid mixing, uniform temperature distribution. Still, their performance is restricted by (i) Decreased bed density with increasing gas velocity, (ii) The non-uniformity of the particle bed with significant bubbling, and (iii) The gas-solid flow velocity, which cannot outweigh the terminal velocity of the particles in gravity.

**Spray dryer:** Spray dryer is a representation of the processing of solution material to a powder form. Fine atomizers are sprayed into a drying chamber, and the powder is stored. Droplet sizes from  $10\ \mu\text{m}$  to over  $100\ \mu\text{m}$  are produced [11]. A layer of viscous slurry at the top of the tower is atomized using nozzles or finely divided by compressed air or a rotating wheel. Upon their fall, the droplets dry to form small particles that are collected and removed from the base of the tower. The drying method requires a considerable degree of fluidity in the slurry to be dried. Typical data collected for various dryers have been outlined in [Tab. 3](#).

Steam dryers provide better drying rates than air and gas dryers. Several dryers have outlet temperatures above  $100^\circ\text{C}$  to avoid condensation of acids and resins [10]. Flash dryers operate at lower temperature and shorter retention time, therefore they are at a lower fire risk than rotary dryers [11]. Rotary dryers are the most basic option for biomass applications and also have low maintenance [12]. Convective dryers such as rotary,

pneumatic, spray and even fluidized-bed dryers have varying drying times [13]. Drying in belt, tunnel and rotary dryers can take more than one hour whereas Pneumatic dryers and spray dryers have a drying time of less than one minute [14]. Superheated steam dryers have a range of advantages compared to air dryers.

### 3.6 Performance Aspects & Process Parameters

Drying equipment generally uses all heat transfer modes to exchange energy from the heat source to the material. The main important process parameter values are drying time and amount of heat required for drying. Again, energy consumption is a very important parameter which affects the drying cost. The various efficiency and performance parameter used by several researchers are listed below. The primary method to assess energy efficiency [ $\eta$ ] is to estimate the ratio between the energy required to dry the product to the dryer's energy. There are other indices like SMER, HUF, and DEF, which are also used by several researchers [14–16]. DEF is a method to recognize the difference between the values of theoretical and experimental efficiency. The higher the DEF, the better is the system design and performance.

Drying efficiency( $\eta$ ) = WL/MC = energy used to dry the food product/energy input to the dryer

Specific moisture evaporation rate (SMER) = Amount of water evaporated/Energy used = kg/kWh

Dryer Efficiency Factor (DEF) = actual experimental efficiency/theoretical efficiency;

Heat utilization factor (HUF) = Heat utilized/Heat supplied =  $(cp_1t_1 - cp_2t_2)/(cp_1t_1 - cp_0t_0)$

## 4 Small-Scale Biomass Dryers: Design Aspects

### 4.1 Design and Components

Biomass dryer is used to dry crops using waste agro material as fuel. Hot gases generated by the combustion of waste biomass are passed through the heat exchanger to the ambient air coming through the blower [15]. The hot, clean air passes through the drying chamber, where the dried crop is placed on the trays. A schematic of the biomass drying system is shown in Fig. 3. The main parts of the biomass dryer systems are showed briefly in detail. 1. Heating or combustion chamber: The firing chamber has a door that should be kept closed when the dryer is working. This helps to undergo the thermo-chemical reactions to burn the fuel well. 2. Duct: It is the central part of the dryer, generally made of mild steel. Air is drawn from the chamber to dryer. 3. Drying chamber: Hot air streams flow into the drying chamber and reduces the moisture content of the product. This is a storage place of the system. The size of the dryer can be modified according to the capacity of this product. 4. Trays: Stainless steel is the right material to make trays because it does not rust due to environmental conditions. The number of trays may increase in the dryer depends on its size. 5. Chimney: The purpose of the chimney is to regulate the gas flowing through the drying chamber to the atmosphere at a height that is sufficiently above the permissible limit.

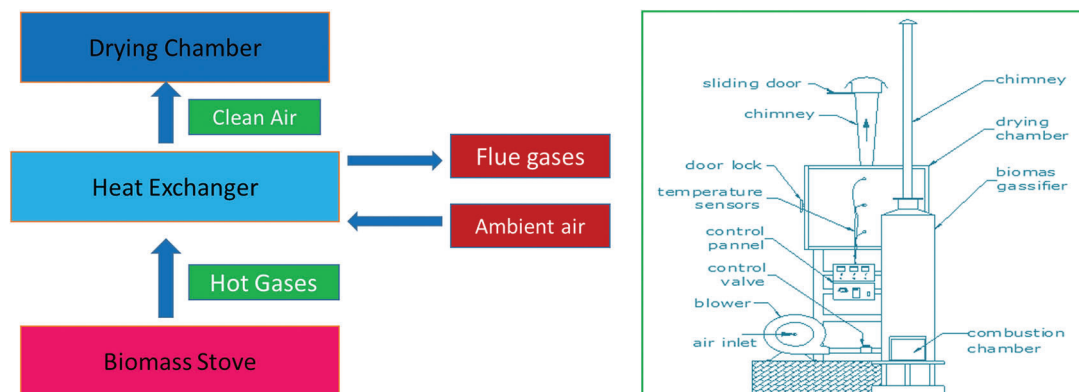
## 5 Summary of Selected Research on Various Small-Scale Biomass Dryer

Recent progress in advances of small-scale biomass dryers are summarized in Tab. 4.

Dhanushkodi et al. [17] investigated the energy consumption of cashew nut processing and compared it with different methods such as electrical, steam, and biomass drying. The total energy consumption for drying 1000 kg of cashew nuts using above methods are 5866.2 MJ, 5911.69 MJ, and 6897.36 MJ respectively. The efficient use of fuel and the drying system based on renewable energy has played a role in reducing the cost of production, and 95% energy was used for drying. The energy intensity of the process ranged from 1.5 to 3 MJ/kg.

Vigants et al. [18] carried out an analysis to assess the energy consumption of biomass drying. The energy consumption with and without the air recirculation for each drying process was modeled. The recirculation of the air increases the overall consumption of electricity and heat due to the increase in the flow rate of drying agents and moisture content at the inlet.





**Figure 3:** Schematic and block diagram of biomass dryer

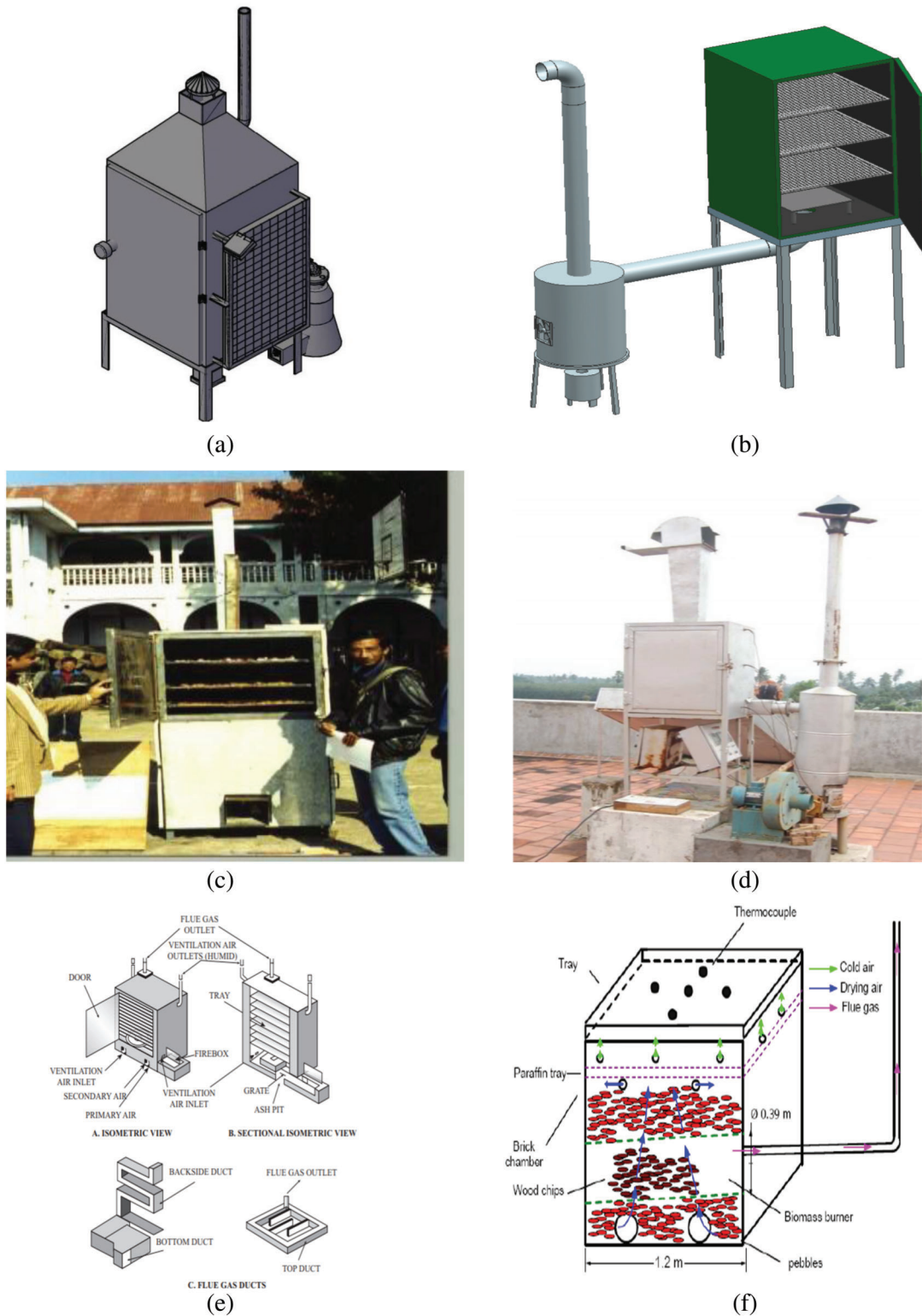
Ozollapins et al. [19] designed a biomass dryer for drying moisture content to develop an efficient method. The drying rates increased with biomass temperature; but decreases once a certain point is reached. The highest drying rate was achieved for reed canary grass at 78°C temperature with initial humidity of 69.7 percent. Pre-treatment in open sun drying is required for biomass with an initial moisture content greater than 30%.

Uthman et al. [20] designed and tested a biomass dryer for agricultural products such as groundnut. It was tested with a weight of 50 g, 100 g, 150 g, and at 55°C, 60°C and 65°C temperature. The temperatures of 60°C and 65°C were much better for drying. Higher the temperature of drying, the lower the time taken for the groundnut to dry; the higher the weight, the less the drying rate. The biomass dryer was recommended for producers and sellers of groundnuts.

**Table 4:** Studies on various biomass dryers for agricultural products

S. No.	Reference/ Literature	Drying type/Place	Agro-Product	Techno-economic/Research findings
1	Uthman et al. [20]	Kwara state polytechnic, Ilorin	Groundnut	An average 3 hours, thirty minutes is enough to dry groundnut at temperature of 65°C, 4½ hours is enough to dry groundnut at temperature of 60°C and 6 hours is enough to dry groundnut at temperature of 55°C.
2	Anju and Sudhakar [21]	MANIT-Bhopal biomass dryer	Chilies	The biomass drier removed moisture content in chilies from 80% to 10%, in 9 h. The combustion efficiency, i.e., the efficiency of the heat exchanger system along with biomass stove, was found to be 30.38% while the drying chamber efficiency was calculated to be 17.83%. The overall efficiency is 5.4%.
3	CSIR, India [22]	IMMT–Bhubaneswar biomass dryer	Agriculture products, food, and industrial materials	Firewood was used at 3.3 kg/hr. The dryer retains a uniform temperature with a high thermal efficiency of 80%. Approximately 60 to 70 % of energy costs & drying time are reduced.
3	Dhanushkodi et al. [23]	PRIST-Puducherry biomass dryer	Cashew	The developed scheme is appropriate for 40 kg of cashew drying. The acceptable temperature range of 65–75°C was obtained with 0.5–0.75 kg/h of fuel consumption. The moisture content of 9% was reduced to 3% within 7 hours. The overall efficiency is 9.5%.
4	Lokras [24]	IISc ASTRA dryer	fruits, vegetables, herbs, spices, papads, etc	Fuelwood is burned in a combustion chamber with a controlled drying rate. Design can evaporate 3 to 4 kg of moisture per kg of fuelwood. Approximately 1,000 ASTRA dryers are in the market. Capacities: 5 kg to 400 kg.
5	Mohapatra et al. [25,26]	IIT Guwahati dryer	Paddy	Woodchips (biomass) are used to heat air. Generates hot air in the range of 60–70°C. Paddy is dried from 33% to 14% (w.b) moisture content.





**Figure 4:** Biomass dryer developed by different institutes. a) Dryer design of Kwara state polytechnic [20] b) Dryer design of MANIT-Bhopal [21] c) Dryer design of IMMT–Bhubaneswar [22] d) Dryer design of PRIST-Puducherry [23] e) Dryer design of IISc-Bangalore [24] f) Dryer design of IIT-Guwahati [25]

## 6 Future Works and Recommendations

Biomass has much benefit for the environment than fossil fuels. Biomass contains a small amount of nitrogen and sulfur, so there are no harmful pollutants from biomass drying. The direct or indirect method of biomass drying suitable for agricultural products, vegetables, and fruits with expected quality and lowest cost are yet to be studied. There has been a considerable industrial application of biomass drying [27–30]. However, there are very few studies regarding direct biomass drying for food crops. Hence, the present summary is unable to disclose any revolutionary technological advancement in small-scale drying using biomass dryers. Nonetheless, on the basis of the analysis, it can be inferred that, for practical applications that make economic sense, energy issues, and the cost of mass production of dried products need to be addressed. It is further well understood that the biomass dryer method is better than other drying methods. Although biomass drying has a significant promise, its commercial application faces a number of key challenges. The following recommendations are provided for the future work on biomass drying.

- Industrial biomass dryers need to be studied more closely on the basis of energy consumption and environmental impacts. The selection of industrial dryers should not only consider the investment costs, but also energy consumption and environmental impact.
- Scale-up of the experimental biomass dryers based on advanced modelling and techno-economic assessment is essential.
- Biomass drying standards should be introduced taking into consideration of sustainability and socio-economic concerns of various drying materials and equipment

## 7 Conclusions

The paper reviewed the design and performance of biomass dryer with advantages and disadvantages, present and past methods of different types of drying. The various designs of biomass dryers have been considered to improve the dryer efficiency and enhancement of the product quality with uniform drying. This analysis provided insight into various biomass drying technology on a small and industrial scale. The following key conclusions can be drawn from the analysis:

- It is generally acknowledged that moisture affects the process efficiency and quality of the product. The quantifiable drying of products inside the drying chamber depends heavily on the heated airflow system and the product characteristics.
- A study on industrial drying showed that dryers have an efficiency ranging from 20% to about 90% for dryers, such as drum, and rotary dryer dryers
- However, there is no detailed research investigation of biomass dryers for food products. It is impossible to recognize up a specific ideal scheme of biomass dryers through the existing literature.
- It can be inferred that biomass dryers may offer a wide range of advantages for drying food products such as groundnut, chilies, vegetables, and paddy
- It is tremendously beneficial to agro-based economies, where surplus biomass potential is available around the year.
- In future designs, significant efforts should be made to improve the technical, economic, and environmental aspects. It might help scientists and researchers to identify and develop a useful dryer to meet the drying requirements.

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