Chapter 6
Challenges in Implementing Proposed Sustainable Food Drying Techniques

Food industry and consumer culture have evolved considerably over the past few decades. Earlier, a simple heat and mass transfer mechanisms were used for extending the shelf life of dried food products. However, as the knowledge about the dried food properties is becoming increasingly available, research and development on drying technologies have expanded beyond the limited mechanical and chemical engineering approach of heat and mass transfer. As a result, improved and efficient drying technologies are not a future dream anymore; it is within reach of people in developing countries. The recent trend is to produce dried food products, which can retain various qualities of fresh food, including texture, nutrition, sensory properties, flavors, and color [1, 2] (see Chap. 2 for details). Modern dryers are expected to have the capacity to produce high quality dried food as well as accomplish the drying process in an energy-efficient and inexpensive way. Chapter 5 discussed and recommended potential drying techniques that can meet the drying industry benchmark and produce improved dry food. In this chapter, the challenges associated with adopting the recommended drying techniques are discussed from the perspective of developing countries. In most cases, the fundamental challenge behind high quality dried food production is to determine the optimum drying condition (operating conditions) for a particular drying technology [3, 4]. A general view of the effects of process severity on the food quality is presented in Fig. 6.1 [5].

When designing energy-efficient, cost-effective, and sustainable drying techniques for developing countries, engineers and researchers should concentrate their focus on challenges associated with drying operation, post drying storage, packaging system, and retention of food quality. Careful evaluation should be done on the financial, technical, and policy-related issues that might occur if a developing country chooses to invest in an improved drying technique. Therefore, this chapter aims to identify the bounds of applicability for the proposed improved drying techniques discussed in Chap. 5. It is expected that future research would one day be able to solve these challenges.

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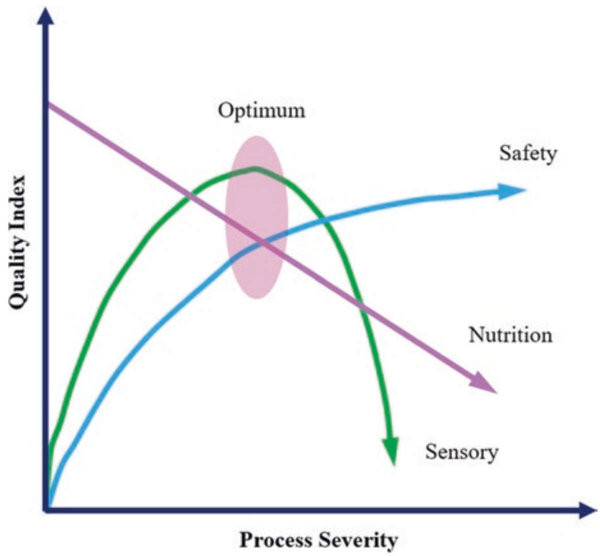

Fig. 6.1 Effects of process severity of food quality

Additionally, the opposing nature of cost feasibility and energy efficiency imposes a complex challenge. The market available drying techniques are two types: the first types have low efficiency, is simple in design, require low-power but is very cost-effective. The other types of the dryer are highly energy-efficient, have long-life but are very expensive dryers. Thus, finding a trade-off between energy efficiency and cost-effectiveness is a challenge. This book, therefore, proposed renewable energy-based improved drying technologies to prioritize energy efficiency in favor of environmental sustainability. This is in part due to the exorbitant cost associated with the climate change crisis.

6.1 Overall Challenges of Drying

Dehydrated foods can appeal to a wide range of consumers irrespective of age and ethnicity. Long shelf life, lower processing cost, and zero preservatives are some of the major benefits enjoyed by dry food enthusiasts [6]. Drying can be done in numerous ways depending on the desired level of food quality, expected drying time, available sources of energy, and type of food material [7, 8] (See Chaps. 4 and 5 for more information). Despite the technical soundness and various benefits, certain challenges are associated with drying systems and processes. Before the specific challenges are being discussed, the general bounds of applicability, which is commonly associated with most dryers, are presented here.

6.1.1 Preparation of Food Samples

Before drying can be accomplished, it is essential to slice the drying fruits and vegetables in an appropriate shape and size. If the samples are too thin, it will dry considerably faster, but there is a risk that its nutritional values, texture, and taste will be lost [3, 4]. In contrast, if food sample slices are too thick, it will take a considerably long time to dehydrate. Longer drying time will increase the cost of the finished product, and the inside of food may not dry properly. Additionally, the dryness level is significantly affected by the volume of food that is added in a single batch. Determining the optimal amount of food, which is to be dried in a single session, can be challenging for general consumers.

Typically, users resort to the process of trial and error to determine the right shape, size of the sample, and amount of the vegetable and fruits to dry in a batch. Furthermore, a lack of knowledge of the operating procedures of an improved dryer might also cause improper drying.

6.1.2 Environmental Cleanliness

While selecting the type of drying technique in order to process a particular food, cleanliness and hygiene should be given top priority. Keeping the dryer clean and sanitized is imperative to producing a high-quality finished product. Over time, the repeated use of a dryer contaminates its drying chamber. Small food particles that get stuck inside the drying trays or small perforated holes can be a source for microbial growth. If the dying chambers are not cleaned after certain intervals, the microbial growth can increase exponentially. In that case bacteria, dust, and debris can deteriorate the dried food quality significantly. Additionally, the operator should use clean utensils for handling the food materials or wash their hands carefully before and after food handling.

Dried food products that are prepared in an unclean contaminated environment are susceptible to bacterial infection. Consumption of such contaminated food might poison the user. Therefore, a significant concern should be given to environmental cleanliness.

6.1.3 Need for Specialized Equipment

In many dryers' special equipment and chemicals are needed to be restocked. Sensitive equipment might malfunction after a number of drying operation and chemicals such as phase change materials, and hypotonic solutions should be resupplied once their stock is over. Therefore, it is essential to calculate the depreciation cost of specialized drying equipment to avoid operational failure.

Additionally, if drying is to be done regularly, it is essential to store the processed food in a safe and contamination-free environment. In developing countries with high humidity, equipment such as dehumidifier and vacuum sealer should be used to make sure the dried food samples do not re-absorb moisture from the atmosphere.

6.1.4 Food Texture

For any dryer, it is difficult to maintain consistency and precise dryness fraction in successive drying operation. Often it is challenging to gain the expected dryness level as slight changes in the drying parameters might produce different quality finished products. Food materials that are dried with high temperatures might crumble if touched. Moreover, uneven heat distribution inside the dryer might form a curst on the side of the food as well as an inconsistent dried surface.

6.1.5 Drying Time

Despite the advancement in the dryer, the drying process is considerably time-consuming. Few drying techniques which offer faster drying are very expensive and difficult to operate. In most dryers, it might take several hours before the food material is sufficiently moisture-free from inside and ready for storage.

6.1.6 Energy Required for Drying

Operating a dryer regularly for several hours a day will undoubtedly consume an enormous amount of energy. If the dryer operates on fossil fuel or fossil-based electricity, it will undoubtedly increase the cost of drying. A considerable percentage of energy in the food processing industry is consumed by the drying and heating process; therefore, the energy factor should be carefully considered [9, 10]. That is to say, for short term benefit of low-cost fossil-based drying techniques should not be prioritized over renewable energy-based high initial investment drying systems. While the fossil-based dryer can operate with inexpensive initial installment costs, due to high operating costs over time, it will prove to be more expensive than any form of renewable energy-based drying techniques. Optimizing the energy efficiency of drying techniques have always been a challenge [11].

6.1.7 Nutrition Content

The quality of dried food has improved significantly over the years due to the improvement of drying techniques. However, no drying techniques exist in the market, which can retain the original nutritional content of fresh food once it is dried. If the drying is done improperly, a significant percentage of the vitamins and minerals of the food sample may be irreversibly damaged.

Furthermore, some dried food becomes rich in salt and sugar once the drying operation is complete. If the salt and sugar concentration is not maintained correctly, once consumed, it might raise the blood pressure of the individual. It has been observed that the salt concentration of dried snacks is above the recommended salt intake level of adults. Drying technologies should be designed to maintain an adequate level of nutrition inside the dried food samples, which is always proved as one of the challenging tasks.

6.1.8 Taste of Food

Often the dried food is too hard or requires moistening up before consumption. In those cases, the consumer might dislike dried food. Improper drying may also damage the soft and tenderness aspects of fruits and vegetables, which is unappealing to many consumers. Therefore, it is vital to ensure that the consumer finds dried food tasty and attractive. Drying techniques should be selected considering the taste factor.

6.2 Specific Challenges in Implementing Proposed Drying Techniques

Chapter 5 has recommended improved drying technologies for developing countries based on specific selection criteria such as drying quality, energy, time, and cost (see Chap. 2 for details). Drying involves heating of drying medium, and in the drying process, a huge amount of energy is lost as it is impossible to utilize 100% of the heat energy. Therefore, all dryers are susceptible to limitations and disadvantages. Specific challenges related to the implementation, maintenance, and operation of the proposed drying techniques are presented critically here.

6.2.1 Challenges in Implementing Improved Solar Drying Systems

Despite the renewable and non-polluting nature of solar energy, it is difficult to use solar radiation for drying. While there is an abundance of solar energy, its periodic nature contradicts the idea of continuous operation. Therefore, the inherent problem of all solar-based technologies is that they are ineffective during off-sun shine hours. Although this issue can be addressed with the use of a thermal storage system, but they have their own list of limitations. Alongside this thermal storage, the difficulty of solar energy can be mediated using auxiliary energy sources. However, that will increase the cost of the entire drying system.

Moreover, since the incident radiation intensity is a function of time, the optimal intensity is available only for 1–3 hours each day. During the morning and afternoon hours, the solar intensity is considerably low. Another glaring problem of solar-based technologies is the low energy density of solar radiation. Because of low energy density, solar dryers require a large collector area, which may be expensive. Considering the fact that fossil-based technologies can supply enormous heat flux using a compact setup, it is impractical for solar dryers to demand large energy-collecting surfaces.

The application of solar drying technologies is also limited by the geographic position of a particular country. Generally, developing countries are situated in the tropical region, which is suitable for solar drying due to high global horizontal solar irradiance. Developing nations situated beyond the tropic of Cancer and the tropic of Capricorn can use solar radiation on a limited scale. Moreover, the performance of solar dryers is also susceptible to seasonal changes, meaning during winter or rainy season, the solar dryers are extremely ineffective. Hence, it is essential to select seasonal crops for solar dryers to govern investment costs. Additionally, only a limited number of food products can be dried using cheaper flat-plate solar collectors, which can heat the air up to 60 °C. High-temperature drying can only be achieved through concentrated solar collectors. However, these types of dryers are considerably expensive. Given the small energy flux of most solar dryers, they can only be used for drying food, which requires low energy.

The congenital problems of solar dryers can be summarized as (i) they require expensive heat storage systems or auxiliary energy source or both (ii) they lack a temperature control system, and (iii) in order to operate efficiently, they need large-surface collectors. The solutions to these problems necessitate high investment, which may be a challenge for the low-income developing countries of the world.

6.2.2 Challenges in Implementing Geothermal Drying Systems

Challenges associated with the adoption of geothermal drying in developing countries can be classified as: (i) financial challenges; (ii) policy and regulation challenges; and (iii) technical challenges. The cause and effects of these challenges are presented critically here.

6.2.2.1 Policy and Regulation

- Although geothermal energy is an accepted form of renewable energy, very few governments of the developing countries have clear policies and legislations for its utilization. Due to the lack of interest of the government, domestic investors and foreign private sectors are reluctant to invest in geothermal energy-based drying.
- Geothermal energy requires a high initial investment and costly infrastructure development. Such financial capacity is unavailable to most developing countries. Moreover, due to inadequate legislative framework, it is challenging to receive funds for geothermal surveys and exploration, which can potentially lower the cost of its utilization. Without the right policy and early phase financial support from the government for research and appraisal, it would very difficult to adopt geothermal dryers in developing countries.
- Most developing countries lack political stability, institutional framework, and consolidation among stakeholders. These are pre-requisite for establishing geothermal energy and drying industries.

6.2.2.2 Technical Barrier

- The adoption of geothermal technologies (e.g., geothermal dryer) requires high-level technical expertise. However, most developing countries suffer from a shortage of qualified geothermal engineers, economic managers, trained labors, and policy analysts to successfully implement a geothermal project. Most geothermal dryers work in association with a geothermal power plant. The rarity of geothermal plants in developing countries is also a significant challenge.
- Developing countries with less advanced communication networks, organizational culture, and transportation systems will find it difficult to adopt geothermal drying technology.

6.2.2.3 Financial Barrier

- One of the biggest challenges of implementing geothermal drying technology is its exorbitant high upfront cost. This situation is exacerbated by the lack of financial incentives (e.g., green tariffs, feed-in tariff) for adopting renewable energy technologies. These renewable energy sources are inherently more expensive than fossil fuels. Therefore, without governmental support and tax break policies, it will be very difficult for private companies to finance renewable energy technology such as a geothermal dryer. It is difficult for low- and middle-income developing countries to distribute their limited budget among different development sectors (e.g. health, education, national security). As a result, the growth of geothermal drying technology might face difficulties.
- Since most low and middle-income developing countries do not yet have a net metering policy, it is a challenge to find foreign investors for financing expensive renewable energy projects. Moreover, without any specific tax break, consumers will not be interested in paying higher for dried food produced using renewable energy. The unfavorable terms and conditions of mutual agreements also drive away potential investors.

6.2.3 Challenges in Implementing Hybrid Geothermal Drying Systems

Scientific research and engineering innovation have given the consumer several ingenious techniques to better utilize the immense solar potential. However, the integration of said technologies with the existing energy framework can be challenging and often requires extensive market research. There are some challenges that are to be faced with implementing this hybrid system. These challenges are described below:

6.2.3.1 Specific Challenges

In the case of Solar Air Heater,

- Air has poor heat transfer properties. Collectors need to be faced towards the sun. Thus, the requirement of the proper sun-tracking facility makes the system challenging.
- The complex geometry of the collector (e.g. V-groove, finned) is required to increase efficiency, but it increases the cost.

In the case of PCM,

- Proper heat distribution inside the PCM compartment is difficult in a practical setup, which reduces the efficiency

- Evaporation of paraffin and its leakage to the environment may lead to economic loss
- The compartment should be stable and compatible to store PCM
- Encapsulation increases the efficiency of PCM, but increased complexity and cost limits its use.

In the case of geothermal energy,

- Geothermal energy collection requires a high initial investment
- Depending on the depth, costly setup is needed, and high power is necessary to make the fluid flow in the geothermal heat exchanger
- Rigorous geological survey is required to find the potential areas for geothermal energy
- Sulphur dioxide, silica, and toxic heavy metal like arsenic, mercury, boron, etc. emission come with geothermal energy.

6.2.3.2 Geographical Challenge

Both the solar irradiance and geothermal energy depends on the geography of the place. It might be challenging for developing countries to locate an ideal place where high solar irradiation is accompanied by high geothermal energy without a comprehensive survey. Besides, the solar collector is required to face the sunlight for most of the time, which makes the system application difficult. Hybrid geothermal dryers will be economically practical and useful, provided that only if the average annual sunshine time (approximately greater than 2600 hr) is high and the yearly total quantity of radiation is enough (more than 6 × 10^6 KJ/m^2) [6].

6.2.3.3 Technical Challenge

Despite the theoretical potential of supplying higher than ambient air temperature for 24 hours a day, the hybrid geothermal PA-FPSC requires electric power to operate its pumps and blowers. In an ideal condition, the pumps and associated electrical systems can run on PV cell technology. However, the average sun hour in developing countries is about 7 hours; hence, after dark, it would be difficult to support the system without appropriate electric power backup. The limitation can be avoided with the application of an electronic battery system, although that would increase the cost of the system. Maintaining the geothermal earth to the air heat exchanger is also difficult.

6.2.4 Challenges in Utilising Heat Pump Drying Systems

Heat pump dryers' advantages clearly indicate that they represent a smart investment in the long run. Limitations of the heat pump dryer are described below:

- Chlorofluorocarbons (CFCs) are used in refrigerant cycles, some of which are not environment friendly. It requires regular maintenance of components (e.g., compressor and refrigerant filters) and charging of the refrigerant, which may incur a higher capital cost [12].
- This process has a lower heat supply compared to oil and gas boilers, so larger radiators would be needed for high-temperature drying. These systems can take significant time to heat up. Additionally, the scheme of collecting the required energy from solar or wind power, may not be a sustainable solution given that they have their own limitations. Without proper insulation, system efficiency will drop significantly.
- These systems are noisy, which is made worse during the winter seasons. Since heat pump dryers have a low Coefficient of Performance (COP), they have low efficiency during winter. As a result, to achieve effective drying, heat pump dryers need to run continuously during winter. This increases the operation cost on top of its high upfront installment cost. The installation cost of advanced heat pump dryers can be as high as 24,500 USD, which is very difficult to afford for low and middle-income developing countries [13].
- Heat pump systems are challenging to install and maintain. Troubleshooting of the heat pump system is not possible without trained professionals. Additionally, the heat transfer fluid used in this system has questionable sustainability. If exposed, they can cause a detrimental threat to the environment. Therefore, companies should use biodegradable fluids.
- Since heat pump dryers require electricity, unless they are operating on renewable energy, these dryers will have a high carbon footprint. Additionally, over-reliance on fossil fuel energy will rack up the operating cost significantly. However, the proposed heat pump dryers with solar integration can effectively produce a zero-energy heat pump dryer. Due to the high implementation cost, it would only be beneficial to middle- and high-income developing countries. In some countries, because of the environmental production laws and regulations, planning permissions might be required for installing heat pumps.

6.2.5 Challenges in Applying Waste Heat Convective Drying (WHCD) Systems

The proposed innovative WHCD system can utilize the waste heat recovered from different sources, including combustion engines, generators, boilers, furnaces, etc. and reuses that heat to dry food for preservation purposes. The proposed process does not require external energy to drive the drying process; therefore, it can reduce entropy and CO_2 emissions. However, the implementation of waste heat convective dryer is susceptible to numerous challenges that are discussed below:

- Fouling Factor will play a significant role in the performance of such dryers. When the WHCD system continues to run for an extended period, carbon particles from the exhaust flue gas may slowly accumulate on the inside surface of the heat exchanger. The fouling factor will increase as the layer of carbon particle thickens. Subsequently, the heat transfer coefficient and overall thermal efficiency of the system will decrease. Life cycle analysis could able to help to determine the maintenance procedure for reducing the fouling factor.
- Air filtration system at the opening of the heat exchanger and the food dryer can improve the quality of dried food. Without proper filtration measures, exhaust flue gas might mix with the drying air and contaminate the food material. The toxicity of the exhaust flue gas particles has a detrimental effect on human health. Therefore, selecting the appropriate filter in order to overcome this challenging issue should be considered while implementing this type of proposed dryer
- Design and integration of heat exchangers for different waste heat sources is a challenging task. Selecting an appropriate material for a specific type of engine or generator is also a complicated task. Because all the sources provide waste heat with a varied range of temperatures. Therefore, a wide range of modelling parameters should be considered. Heat resistive materials are required to design heat exchanger for high-temperature exhaust gas. These materials are expensive and difficult to obtain.
- The initial cost could be higher as different parts, including a PV cell, are costly. Therefore, the payback period could be high, which may be difficult to afford for low-income countries

6.2.6 Challenges in Applying Desiccant Drying Systems

Desiccant system was built and tested by Lof in 1955 at Solar Energy Research Institute, University of Wisconsin [14]. It used liquid triethylene glycol in order to heat the air directly inside a solar collector as well as to re-generate the desiccant. The disadvantage of this system was the leakage of desiccant into the cooling space. When desiccants with corrosive nature were used, it proved to be hazardous to the human operator and material near it. Also, such difficulties render it totally unusable in domestic appliances.

Additional limitations include:

- High initial setup cost of the system is a challenge for the developing countries. Experienced professionals are required to construct, install, and service such systems. Liquid desiccants could be corrosive and could damage the system components.

- These are cost-effective only when there is a source of waste heat available to regenerate the desiccant. Regeneration system is complicated to build and maintain. Limited application in high humidity climate areas. System effectiveness, to a large extent, depends on the desiccant properties. Desiccant materials are costly, and to utilize the immense solar potential better crystallization of aqueous salts is an expensive system with high level of complexity.
- When using liquid desiccants such as lithium bromide, lithium chloride, and other salts that are corrosive, the operators should be extremely cautious not to damage the desiccant dryer. If the desiccant and exhaust air are exposed to the environment without proper filtration, it would be detrimental to human health.
- High power pumps are required to handle and operate large quantity of liquid desiccant, which increases the operation cost of desiccant drying beyond the reach of low-income developing countries.

6.2.7 Challenges in Applying Improved Biomass Drying Systems

Implementing an economically feasible and environmentally sustainable biomass drying technology can be a challenging task [15]. In this sub-section, a summary of the challenges associated with biomass drying is represented.

6.2.7.1 Thermochemical Conversion

Biomass feeds are thermochemically converted (e.g., combustion and gasification) into usable thermal energy for the dryer, which has some shortcomings. Wood chips are primarily used as biomass fuel for combustion-based dryers, which raises major environmental concerns due to carbon pollution [16, 17]. Additionally, excessive use of wood chips may promote deforestation. Unplanned irradiation of natural resources will disrupt the ecosystem and damage biological diversity.

6.2.7.2 Physical Conversion Techniques

Improved cooking stoves and biomass briquetting widely used for biomass combustion inside the dryer. When biomass is burnt in these dryers, an enormous amount of NO_x and particulate matter are released into the environment. These toxic particles have adverse effects on the ecosystem, including acid rain, photochemical smog, and disruption of crop production [18]. Furthermore, the physical conversion of biomass inside the dryer may release by-products such as sulphur oxides (SO_2, SO_3), which have detrimental effect on environmental sustainability [19, 20].

6.2.7.3 Operational Challenges

- The generation of feed material for biomass dryers requires valuable resources like water, land, and energy. Without proper management of these resources and governmental financial support, it is challenging to grow the feed material industry. With the growing demand for drying technologies, if the feed material supply does not increase, the biomass dryers would not be able to function economically.
- Transporting wet biomass is a challenge because of its high moisture content. The presence of moisture not only makes it difficult to handle but also increases its weight. The growth of microbes and odor also makes it unfavorable for storing near food processing industry.
- Inefficient design of biomass combustor produces low thermal energy, which may improperly dry the food products. Conversely, efficient combustors are difficult to maintain and often expensive. Moreover, the lack of appropriate pre-treatment process accelerates biodegradation and increases the loss of heating value. As a result, the production and equipment maintenance cost of biomass dryer increases.
- Due to lack of communication, it has proven to be very difficult to keep long term sustainable contracts with biomass feedstock suppliers at an acceptable price. The minimum profitability of the biomass feed industry makes it difficult to attract private companies to support the upstream firms for producing biomass feed for the dryer.

6.2.7.4 Economic Challenges

- Since the biomass resources are scattered in small regions isolated from each other. It is expensive to transport biomass feed from one place to another. Most dryers are installed along with food processing industries; therefore, high transportation costs involved in ensuring a constant supply of biomass feed will be challenging.
- Owing to lack of capital, subsidies on feed production, inadequate profitability accompanied by a low number of investors, and high market risk make it very challenging to invest in biomass drying.

6.2.7.5 Policy and Regulation

- In many developing countries, there are no concrete regulations or financial incentives for utilizing biomass energy. Therefore, companies do not have an economic interest in investing in biomass energy-based dryers.
- Due to the lack of a special mechanism for managing and developing the biomass resources industry, it is difficult to find the biomass feeds at low prices.

Since most developing countries do not have a feed-in tariff or green tariff on biomass energy, this industry is severely underdeveloped.

6.2.8 Challenges in Applying Hybrid Solar-Biomass Drying Systems

Challenges associated with hybrid solar-biomass drying is a combination of the challenges discussed in the solar and biomass drying. Since this is a hybrid system combining the potential of solar and biomass energy, some advantages may ameliorate the disadvantages of others. As such, the potential challenges associated with this dryer is discussed as follows [21]:

- Solar energy and biomass energy both require a large amount of land to establish its infrastructure, which is difficult to attain in developing countries with high population density. Additionally, a constant supply of feed materials should be ensured for the continuous operation of this dryer. Feed materials are available in rural areas; hence, these dryers cannot be installed in city or industrial area.
- Transportation of feed material may increase the operational cost of this dryer. Large-scale application of this dryer might contribute to deforestation and subsequently damage the environment. Production of low moisture high energy-dense Agri-pellets is costly.
- In seasons where the solar energy is unavailable, the hybrid dryer will run entirely on biomass energy. As a result, the operating cost will increase significantly. Moreover, long term use of biomass feeds might deplete soil fertility and nutrition, which might also damage biodiversity and disrupt the ecosystem.
- If the governments of certain developing countries do not stop subsidizing the fossil fuel industry, renewable energy-based technologies will find it difficult to penetrate the market. Since the cost of electricity is low, consumers and food industries will resort to using cheap fossil-based electricity for drying purposes.

6.2.9 Challenges in Applying PMSD Systems

Pulsed Microwave Solar Dryer (PMSD) is introduced with an aim to develop an efficient and economically viable drying system, which can operate using renewable energy sources (e.g. solar energy). Although the system has a high degree of compactness and flexibility, there are some specific challenges associated with the implementation of PMSD. An overview of the challenges associated with the PMSD is given here:

- The major challenge in any microwave system is the non-uniformity of the electric field [22, 23]. Without a uniform electric field distribution, the drying temperature and moisture distribution will not be uniform, which will produce low quality dried food.

- Optimizing the pulse ratio for different food materials is very difficult as the different food materials have their unique characteristics [24, 25]. Furthermore, there are numerous ways by which the pulse ratio of the microwave can be selected, and choosing the exact on-time and off-time of microwave is a challenging task. Moreover, there is a wider variety of process conditions and food properties, selection of these conditions and properties while optimizing the microwave is also a tough task. It is often challenging to maintain a satisfactory quality of the food due to improper selection of pulse ratio that leads to crust formation [25, 26]. Moreover, samples may burn in different places due to the non-uniformity of electric field.
- There will have considerable risk for microwave leakage that will subsequently affect the uniformity of the electric field. High-intensity microwave radiation might cause physical damage to the operator; therefore, proper protection should be used.
- If the system runs on solar energy, it would be difficult to operate during the off-sunshine hours without expensive battery backup. Moreover, PMSD is a costly technology that requires a high initial investment, as it consumes high voltage electricity, which is expensive.

6.2.10 Challenges in Applying Osmotic Dehydration Systems

It offers considerable potential for energy saving in comparison with conventional drying. However, most researches on the energy consumption and efficiency of osmotic dehydration were done or analyzed under laboratory conditions [27–30]. These parameters might change when the drying technique is used as part of the large-scale production industry. Therefore, the effectivity of osmotic dehydration in practical scenario might face the following challenges [31]:

- The Osmo-active solutions require constant heating to regenerate its dehydration capacity. Supplying constant heat may require additional investment and operators. The cost of additional heat energy will increase its operating cost of the dryer.
- A complicated control system is required to ensure proper solution mixing and recirculation. It is difficult to operate the control system of the dryer without the help of an expert.
- After the successive operation, the hypertonic substance dissolves and becomes diluted, which may produce low quality dried products after certain operation cycles.
- An expensive evaporator is required for appropriate evaporation of water, which will considerably increase the instalment cost of the dryer

Being constrained by the laws of thermodynamics, it is near impossible to create a drying system with Carnot's efficiency. Therefore, all proposed dryers are subjected to various forms of physical and implementation related challenges. Improved drying techniques are recommended despite their respective limitations due to their environmental sustainability and cost-effectiveness in the long run. It can be hoped that the government and private sectors will form a synergy and work together to overcome some of the policy and financial challenges. If the challenges can be solved by any margin, it will significantly improve the economic condition of developing counties, and above all, a green environment can be assured by doing so.

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