A Review on the Effects of Drying and Humidity on Food Products

Mandar Phalak and Devajyoti Banerhee

June 4, 2022

A review on the effects of drying and humidity on food products

M.G. Phalak[1] Devajyoti Banerjee[2]

[1-4]University Department of Chemical Technology Kavayitri Bahinabai Chaudhari Maharashtra University Jalgaon 425001

[4]Department of Chemical Engineering, Gharda Institute of Technology, Lavel, Maharashtra – 415708, India

---

Abstract:-

Drying is one of the oldest techniques of food preservation that removes the water content from food and ensures uniform consumption throughout. The frequent usage of drying techniques includes diffusion dehydration, vacuum drying, freezing, and completely different combinations of alternative drying techniques. The processes occurring due to heat and humidity in an external wall of heated buildings are the result of external climatic conditions. The drying practices are not only limited to mathematical issues for the drying mechanism but also affect the potency of dryers, which increases the value of production and cuts back the standard of the dried product. The mean diameter of 20 +/- 0.025 mm was stark naked and sliced into a thickness of 1.233 +/-0.029 mm. They were then dried at a temperature of around 40 to 700C for 120min. Based on the mechanism of heat transfer, drying can be classified into direct (convection), indirect or contact (conduction), beaming (radiation), and dielectric or microwave (radio frequency) drying. In some cases, complicated heat and mass transfer processes are also important factors in drying. This review article aims to a better understanding of selecting the right drying equipment and understanding the science behind the drying process, including thermal properties.

Introduction:-

The drying process is one of the oldest processes used in industries. The air temperature surrounding the pellets is at a higher temperature than the air itself, as the air holds more water and the diffusion rate in the pellets is faster. The higher moisture content requires more time to remove and reduce the moisture content to an acceptable concentration. Airflow around each pellet is critical to removing wet air and replacing it with dry air. The time and temperature needed to dry various polymer resin systems vary greatly depending on the plastic's heat resistance, melting or softening point, and thermal resistance. The drying time decreases with an increase in temperature and a decrease in thickness. The hygroexpansion here in turn is determined by the polymers that make up the fiber and the ultrastructure of the fiber. This review therefore starts with the effect of the smallest unit— the polymers— before advancing to the fiber, chemical modification and the treatment of fibers during production andconcluding with the formation of the fiber network, the effect of paper laminates and an overview of expansion models.[44]The mass transfer is controlled by the water concentration gradient across the food.The temperature gradient between the fruit surface and the drying atmosphere and the relative humidity (and hence air velocity) are all likely to affect the evaporation process.[50] Color is a very sensitive parameter in terms of the influence of drying methods.[54] The basics and advancements of different trivial and modern food preservation techniques, which are attributed to impede food spoilage and to yield longer shelf life, are discussed here along with their mechanisms, application conditions, advantages, and disadvantages.57

The drying process involves using heat to vapourize the water present in the food and remove the water vapour from the food surface[21]. It combines heat and mass transfer for which energy must be supplied. The use of hot air flowing over the food is the most common way of transferring heat to a drying material, mainly by convection. Although drying is an alternative to extending the shelf life of food and also facilitating storage and transportation by reducing the need for expensive cooling systems, it is a fact that the quality of dehydrated food is usually reduced as compared to that of the original foodstuff. [22] This has been made possible by major advances in web-support technology, shoe pressing technology, drying technology and the ability of new surface treatment equipment to deliver superior sheet runnability at high efficiency.[47] A significant amount of this water is removed in the forming and press sections, with typical moisture content after the press section at 56% (46-50% for shoe presses).52 in their review mainly focused on the high intensity dryer concept which is based on impingement drying on large diameter Yankee cylinders. The effect of some parameters such as operating conditions, geometrical conditions, adding of reflectors, heat exchanger heat pump, photovoltaic source, air circulation mode, and phase change material on the efficiency of solar drying system was reviewed and discussed.[55] Conventional drying methods (such as those involving the use of hot air, fluidized beds, and vacuum (VC) drying) are used for postharvest treatment of agricultural products; however, hot-air (HA) drying has its inherent limitations.[58]

The multi-cylinder dryer is a large body of cast iron cylinders typically over 100m long, and there are many incentives for reducing the length, increasing the speed and controlling all the different paper quality parameters.[43] To reduce the use of fossil fuels, electrical energy is an alternate source of energy for drying applications, especially where electricity is generated by a renewable energy source such as hydropower or wind power.[23] Drying consists of complex mechanisms, such as physical, chemical, and biochemical reactions, making it an unsteady, extremely non-linear, and dynamic, thermal process[24]. However, drying may also lead to undesirable quality changes[25], such as altering food quality parameters, such as The Colour of celeriac slices was determined by two readings on the two symmetrical faces of the slice in each replicate using a Minolta CR 400 colorimeter calibrated with a white standard tile. The colour brightness coordinate “L” measures the whiteness value of a colour and ranges from black at 0 to white at 100.[26-31], Diffusion coefficient increased with time until critical moisture was achieved, then stagnated briefly, and after that decreased proportionally with the decreasing moisture content in the material[27], rehydration ratio[33], The fresh and the dried celeriac were subjected to a DPPH free radical spectrophotometric assay for their antioxidant activity assessment.[28], and The phenolic compound is one of the nutritional quality benchmarks during drying[26].In this operation, the moisture content present in a material evapourates because of heat and matter exchange between the product and the working medium.[1]

The moisture content by substances over the equilibrium moisture (x-x*) have only free moisture that can be evaporated and the free moisture content of a solid depends upon the vapour concentration in the gases.

Many solid exhibits different equilibrium moisture characteristics depending upon whether the equilibrium is reached by condensation or evaporation of the moisture. If the solid must be kept at a lower moisture content, it would be a package or stored immediately out of contact with the air in a moisture impervious container.

In calculating dryer requirements, the two separates must be considered at

1) The airflow volume required for drying at the necessary rate.
2) The heat capacity required for drying at the necessary rate measured in BTU per hr.

The water removal rate is also the rate of mass transfer from the solid to the ambient air. These two mass and heat transfers must predict the same rate of drying for a given set of circumstances. The first stage represents a “settling down” period during which the solid surface conditions come into equilibrium with the drying air.[2]

The drying process affects the quality of a dried product. Drying methods used for root crops and starches include solar drying, drum drying, spray drying, freeze drying, microwave drying, and hot air drying.11 durability of external elevation work in a heated building and going thermal and humidity processes depends essentially on the factor of the external climate. They include air temperature and relative humidity, rainfall, wind speed and direction, and solar radiation. The most destructive factor is the humidity which is in connection with the temperature regulator that contributes to decreasing the usage parameter of built-in materials.[3]

Effects of parameter on drying:-

The inlet air temperatures used in this experiment, are very high compared to other normally operated techniques at temperatures ranging between 50°C to 70°C for drying grains.[13] The drying temperature is the important parameter that influences drying speed. At temperatures above the glass temperature, the diffusion rate rapidly increases. However, it is not possible to increase the drying temperature as required, as this can thermally damage or melt the material. The dry airflow transfers heat energy to the material, causing the moisture in the granules to evaporate and dissipate. The airflow volume will also have an impact on drying speed, but once again it cannot be simply adjusted as required. Although a higher volume of air will translate into faster dehumidification, it can also destabilize the material and cause a fluidized bed or can lead to over-drying. During the drying process, the control of air temperature and its circulation in the system is an important factor. If the temperature is too low and the humidity is too high, the food will dry more slowly and microbial growth may occur. Important factors affecting drying rate areas are, Initial moisture content of the raw material, Composition of raw material, Initial load of the food kept in drier, Size, shape, and arrangement of stacking of the raw material, temperature, relative humidity, and velocity of air used for drying, Rate of heat transfer on the surface of the food,[14]

Pre-drying treatment Procedure for drying

Fruit and vegetables and other paper mills are selected and sorted according to size, maturity, and soundness. They are then washed in running water to remove dust, dirt, insects, mould spores, plant parts, soils, debris, and other materials that might contaminate the final product's colour, aroma, flavour, or taste. Depending upon the type and quantity of products to be dried, any method of peeling can be selected like hand peeling, steam, hot water, lye peeling, or abrasive peeling. Fruits like grapes, plums, and apricot are dipped in boiling caustic soda (0.5% NaOH) for a few seconds and immediately placed in cold water to remove the waxy layer, pubescence. After peeling and washing, the fruit and vegetables are sliced or cut into desired size and thickness as it affects the rate of drying.

Dehydrator Dryer

A dehydrator dryer is used for dehydrating food and is an ancient method for preserving food. It is a delicate, process that removes the water content from food. Using a controlled heat temperature, the air is circulated from the top of the unit to each of the five trays and base. This method of drying seals in the flavour and nutrients of the food, leaving a high food nutrient and vitamin content.[42] Natural healthy snacks will simply be created by exploiting the Food dehydrator. A variety of fruit rolls like pear, berry, and apple rolls, to name a few. You can build tasty, breakfast food bars, and exploit all-natural ingredients.[4]

Humidity effects in dryers:-

Humidity affects the dryness that is in contact with the solids. A dynamic equilibrium is set up between the moisture in the solids and the vapour in the air. Solids exposed to moist air for an extended period will reach their equilibrium moisture content, which rises as relative humidity rises or the temperature falls. As a result, solids in a cool, damp atmosphere will pick up more moisture than those stored in warm, dry conditions. XE is often plotted as an adsorption or desorption isotherm.[5]

Effect of drying temperature on drying time

Moisture content during the drying process was measured every 10 min for about 120 min and followed by that it should be converted into a moisture ratio, the effect of drying temperatures on moisture ratio. At the same observation time, the higher drying temperature resulted in a lower moisture ratio. With an increase in drying temperature from 40^0C to 50^0C, the moisture ratio was 0.5 times lesser. Compared to infrared drying, the performance of this method was higher. At a temperature of 40^0C and an operating time of 120 min, infrared drying reduced the moisture content. The temperature has a significant impact on the water solubility in synthetic ester and on the hygroscopicity of cellulose. The higher the temperature of the ester, the more water can dissolve in it. The opposite is true for cellulose materials, for which an increase in temperature means a decrease in hygroscopicity. The reason for this decrease is the value of the energy of hydrogen bonds which is comparable with the energy of vibration of the cellulose molecule.[45]

For each drying temperature, effective moisture diffusivity was calculated using Fick's model,

$$mRt = \frac{8}{\pi^2} \exp\left(\frac{-\pi 2Det}{4L^2}\right)$$

The effective moisture diffusivity values obtained from this research were superior compared to those of the infrared drying method however, they were still smaller than those of fluidized bed working at a faster air velocity and those of microwave. the parameters of the Arrhenius correlation, namely, activation energy and effective moisture diffusivity constant, were reported and validated. Using these validated parameters, De and drying time at any operational temperature can be estimated.[14]

concept of drying

Supposing the drying process occurs on the initially saturated material, vapour leaves from evaporation surface driven by vapour pressure difference until it gets equilibrium with the surrounding environment. The drying process is generally composed of two phases. In the first phase, the vapour pressure at the air-material interface keeps saturated until no more liquid is delivered onto the evaporation surface, which can be described as a linear line of the moisture loss versus time. The evaporation brings the cooling effect, thus the surface temperature decreases. This phase is mainly governed by the boundary condition. When there is no sufficient liquid conducted to the surface, the water front is receded from the evaporation surface into the material. The drying process steps to the second phase, during which moisture migrates to the surface by vapour diffusion.[46]

Effect of relative humidity on drying time:-

Equilibrium moisture content is the water loaded in a material at a certain temperature and relative humidity. By decreasing the relative humidity, the equilibrium moisture content is reduced, which enhanced moisture content reduction. Relative humidity can be reduced in three possible ways: increasing operational drying temperature, removing moisture in the air, and combining these two is the relative humidity that was varied at different drying temperatures to identify an optimum drying time.[14] When the component was dried with direct ambient air (temperature ¼ 30^0C and relative humidity ¼ 70%) as in the case of sunlight drying, the equilibrium moisture content was 0.17 kg water/kg dry solid. This result suggests that moisture content in a component cannot reach a 10% wet basis or 0.11 kg water/kg dry solid, suggesting that the component product cannot be completely dried. Note that decreasing the air relative humidity (suppose using an air dehumidification unit) can be an option to dry the component in medium or low temperatures. Using this method, the driving force of component drying can be improved as indicated with a reduced drying time, e.g., in a drying temperature of 40^0C and air relative humidity of 40%, the component can be fully dried in 172 min. With air relative humidity close to 0 and temperature at 40^0C, the drying time for components was ~110 min.

1. **Different methods used in Drying:-**

There have been many advances in drying technology, including pretreatments, techniques, equipment, and the quality of the final products. Pretreatments include accelerating the drying process, enhancing the quality, and improving the safety of foodstuffs. Besides that, they also help to decrease energy needs. [40]

Water loss from foods is a very energy-intensive process. Drying involves considerable energy consumption: 20–25% of the energy used by the food processing industry or 10–25% of the energy used in all industries in developed countries. Hence, energy, together with time efficiency, represents one of the most significant designs and operation parameters in food processing. Low thermal conductivity and casehardening of materials are the main factors responsible for slowing down convective drying. There have been many advances in drying technology in recent years, including pretreatments, techniques, equipment, and the quality of the final products. Pretreatments, for example, are used to accelerate the drying process, enhance quality, and improve the safety of foodstuffs. Besides, they also help decrease energy needs.

1.1 Hot Air Convective Drying:-

The convective drying of porous media, including foods, has a pivotal role in several industrial applications. Because of its high availability and moisture saturation capacity, the air is unquestionably the most commonly used drying fluid10. The methods in which hot air is used for drying foods are very versatile and have considerable importance. These include drying in chambers with trays or in tunnels equipped with conveyor belts, in rotating drum driers, or even in fluidized bed driers.[12]

1.2 Spray Drying:-

Spray drying is a widely used technique to convert a liquid state into a powder form. It is used for solutions or slurries that go through an atomizer or spray to divide the material into droplets (10-200 μm). The quality of spray-dried microcapsules is quite dependent on the processing parameters of the spray dryer and the properties or composition of the feed solution[12]

1.3 Microwave Drying:-

This method provides a high heating rate and does not cause alterations on the surface of the food hence, no crust is formed. The industrial microwave treatment is limited due to its high cost and the need to synchronize the generator for different foods. Thus, it is used industrially for low moisture foods, or as a final stage of the dehydration process. Microwave drying is an efficient method for post-harvest processing of agricultural products due to its time efficiency, low energy consumption, and high product quality, which are major factors to be considered by the industry. With the development of new technologies, more parameters can be monitored and controlled during the drying process, such as temperature, weight, power, or odour [17.]

1.4 Radiofrequency Drying:-

The use of radiofrequency energy for dielectric heating of food materials is an important application area that has been studied as a possible method for drying agricultural products. The radiofrequency heating directly addresses the product so that its interior is heated faster than its surface. The water is released without overheating or dehydrating the surface. Therefore, it can be used as a complement to other drying processes and allows one to reach very low humidity levels, of the order of 1 to 2%, with minimal impact on quality. This novel drying method provides a shorter time, higher energy efficiency, and better product quality as compared to conventional hot air heating. [18]

1.5 Tray Dryer

Tray dryers are classified as batch type and band dryers and can dry almost everything. However, considering the labour requirement for loading and unloading, they are expensive to operate. They notice the most frequent application when valuable products like dyes and prescribed drugs are concerned. This type of appliance is often used for drying wood and various agricultural product.[21]

Kinetic model of drying:-

Drying kinetics models does not take into account the effects of interactions by parameters other than the time of drying. Models that incorporate a large number of variables still do not exist but due to the complex non-linear relationship between the kinetics of drying and variables related to the development of such models is not feasible[6]. The concept of thin-layer drying models for characterizing the drying behavior was suggested, initially, by Lewis who derived the semi-theoretical model for porous hygroscopic materials, which is analogous to Newton's law of cooling. The following model was developed.[7]

$$MR = \frac{x - x_e}{x_0 - x_e} = \exp(-kt)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where,

MR is moisture ratio,

k is drying constant (m−1m−1),

t is drying time,

XX, XeXe, XoXo are moisture content at any time.

modified the Lewis model by adding a dimensionless empirical constant (n) and used it to study the drying behaviour of shelled corns.

$$MR = \frac{x - x_e}{x_0 - x_e} = \exp(-kt)^n\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots2$$

Characteristics of Drying Curve

The theoretical foundation for the concept of the characteristic drying curve is examined by considering the drying out of a porous, non-hygroscopic slab to an infinite extent. Under intensive drying conditions when a drying front appears, the characteristic drying curve is a function of the relative intensity of drying, whereas under less intensive drying conditions it is not. In the limit of the slow drying of thick, fairly impervious materials, a single linear characteristic drying curve appears.

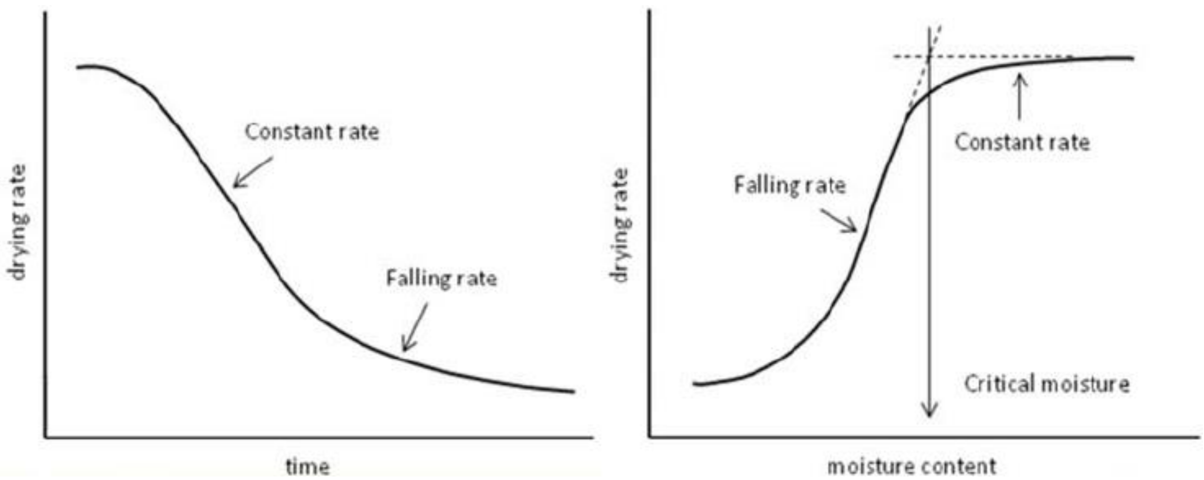

Fig. Characteristics of Drying Curve[27]

The moisture ratio during the drying of ginger was calculated using the equation,[16]

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

Effective Moisture Diffusivity

Fick's second law equation was used to calculate the effective diffusivity value (Deff), where the equation is expressed as,[15]

$$MR = \frac{8}{\pi^2} \varepsilon \frac{1}{2n+1} Exp(\frac{(2n+1)\pi^2}{4L^2} * D$$

Where, D- effective diffusivity value

$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 * D}{4L^2}\right)$

Then equation can be linearized into

$$\ln MR = \ln \frac{8}{\pi^2} - \frac{\pi^2 * D}{4L^2}$$

Response Variable

1. **Moisture Content and Drying Time**
   Moisture content (db) was determined for every 5 min. The drying tray was re-removed from the dryer, and the bottom was dried and weighed. A balance was used for the same.[37] The initial and final moisture content of the sample was determined by oven drying at 70 ◦C for 24 h.
2. **Temperature Profiles**
   The temperatures of the hot water, the water–film interface, and the film-water-food interface were measured every 5 s using J-type thermocouples and a data acquisition system, with an accuracy of 0.2 ◦C.[38] A thermographic camera was used to measure the temperature of the food–air interface.
3. **Radiative Heat Flow**
   The radiative heat flux emitted by the water, the water–film system, and the water–film–food system was measured for all experimental design conditions. A potentiometer with a radiation measurement scale between 0 and 10 W and an accuracy of 0.1 mW was used. This equipment used a pyroelectric sensor to measure the radiation heat flux in a spectral range of 0.25 to 11 μm (from ultraviolet to infrared). The diameter of the measuring sensor was 19 mm.[39]

Drying Kinetics Model Fitting

The drying dynamics curves of each experiment run were created by plotting drying time against moisture ratio. The drying experiments were tied to 11 mathematical models commonly used for thin-layer drying[35]. Those mathematical models are semi theoretical and empirical model[35]. The use of these 11 mathematical models compared to fewer numbers the advantaged of having a greater chance of searching mathematical models applicable in describing the behaviour of celeriac during the drying process. Studying drying kinetics is a means to choose appropriate drying methods and to control the processes of drying. It is also important for engineering and process optimization. It is sometime expensive to conduct a full scale experiment to determine the suitable condition for drying. Drying kinetics is used to express the moisture removal process and its relation to the process variables and hence, a good understanding of the drying rate is important to develop a drying model.[56]

Table 1. Examples of freeze-dried fruits with various operational parameters[17]

Dried material	Shape	Freezing temperature	Pressure	Drying time	properties
Rasberry	Whole	-20	1Pa	48hr	shrinkage, color change
Strawberries	35cm pieces	-20 and -80	15-200Pa	60-65hr	rehydration ratio, appearance, shape, color
Kivi	Whole fruit	-40	12,20,42,85, 103Pa	24hr	Color, texture, rehydration, total phenolic content,
Banana	Dia 2mm Height 8mm	-35	3-300Pa	24hr	Volume, bulk density, glass transition temperature, porosity
Blueberries	Whole fruit	-31	13Pa	24hr	Mass transfer, drying time, berry-busting, skin perforation

Mechanism of heat transfer in drying

Heat transfer and mass transfer are critical aspects of drying processes. Heat is transferred to the product to evaporate the liquid, and mass is transferred as a vapour into the surrounding gas. The drying rate is determined by the set of factors that affect heat and mass transfer. Solids drying is commonly thought to have two distinct drying zones, known as the constant-rate period and the falling-rate period. The two zones are demarcated by a breakpoint called the critical moisture content.[9]The temperature difference is the driving force for heat transfer. So, heat transfer exchanges thermal energy from a high concentration to a low concentration between physical systems. There are three modes of heat transfer, namely, conduction, convection, and radiation. Mostly, conduction and convection modes are used for drying products. [41] The heat flux to the paper is directly related to the drying rate. the drying curve and the distinct drying zones for softwood SW lap pulp and recycled paper. The first zone is the warm up zone where the drying rate increases continuously. The second zone is the constant rate zone. In this study, the second zone lasts for less than one second in all the drying experiments. The next zone is the first falling rate zone. The moisture content between the constant rate zone and the first falling zone is the critical moisture content.[48]

Energy in drying is in the form of heat, and heat is the simplest form of energy and travels from hotter to cooler medium. Heat leaving away from the system towards the surrounding gives negative heat transfer rates and vice versa. Generally,[8] heat transfer is:

$$Q= mC - pT$$

Heat Requirements for Vaporization

The energy, which must be supplied to vaporize the water at any temperature, depends upon this temperature. The quantity of energy required per kg of water is called the latent heat of vaporization, if it is from a liquid, or latent heat of sublimation if it is from a solid.[51]

Size or Thickness of the Material:

Water removal in a drying process depends on how far the water has to travel from the centre of the material to its surface. For this reason, large pieces of food tend to dry more slowly than smaller pieces of the same food. To facilitate drying, it is often best to use pieces which have a small diameter or are not excessively thick. While this factor is closely related to the shape of the material, it is worth mentioning on its own.[49]

Importance

In this review, four prominent features of the dryer are discussed – quality as well as economic, environmental, and social aspects.

1. Quality aspects

Various physical, chemical, and biological process characteristics undergo modification during food drying. This all happens due to mass and heat transfers. It was reported that when it starts to dry with the use of air, it reduces colour changes and volume shrinkage of dried pistachio bonkers compared to sun drying. It was shown that a brighter colour was ascertained in dried lemon samples under complementary drying and when the samples were dried by hot air at 60 oC. The loss of bioactive compounds depends on the properties of the drying air, notably on the temperature, which may result in the solubilization of compounds that are absolute to insoluble fibre parts within the product or freed by cell membrane breakage. They report that the retention of provitamin obtained from star drying of some bifoliate vegetables, like head cabbage, beet, amaranth, and fenugreek, was corresponding to results from cupboard drying at 650C. Bechoff et al. (2009) conjointly found that star and sun-drying weren't significantly different in terms of the provitamin content in orange-fleshed sweet potatoes. When compared to a hot air appliance at a constant temperature of 42 oC, hot air cross-flow drying maintained a lot of provitamins. Similarly, Bengtsson et al. reported that outdoor sun-drying caused the next loss of all-trans-β-carotene after star drying. In a study by Mehta et al. (2017), it was documented that a lot of the practical compounds, like flavonoids, polyphenols, and vitamins A and C, were maintained in solar-dried bitter gourd and capsicum pepper plants, compared to hot air and outdoor preserved samples. [10.]

2. Economic aspects

Assessing the economic viability of investments in solar dryer technologies requires detailed financial and economic appraisals, as such investments are made based on perceived economic and technical viability. Like other similar commercial dryers, the solar dryer is known to be a capital-intensive method (Tiwari, 2016). In addition, compared to traditional sun-drying methods, solar dryers offer several economic advantages that have low costs for fossil fuel and combustion equipment. They have achieved high-quality results and thus increased the market value, which was secured, stable, and had a high income even under various climatic conditions. The use of solar dryers enables small-scale producers to significantly reduce post-harvest losses in a cost-effective and energy-efficient manner, improve the quality of food and generate additional income and employment opportunities. [10]

3. Environmental aspects

Fossil fuels and electricity are widely used as energy sources in most drying systems, which results in high operational costs and environmental problems by increasing greenhouse gas (GHG) emissions. As food producers have shifted towards clean energy-based technologies such as solar and thermal energy, both direct and indirect, it is suggested that the energy usage of the solar dryer could be computed using indicators such as embodied energy, and time to energy payback, CO2 emission, and carbon mitigation. It was found that at an efficiency level of 40%, a solar dryer system can decrease conventional energy consumption by 27–80%. indicated that the power consumption of the fan in the forced ventilation greenhouse dryer accounts for 5% of the total energy. The combination of solar and conventional energy could save 20–40% of energy. The report shows that a hot-air drying system emits about 15 tons/year of CO2 when operated with electrical energy at 100 kWh/day and 25 days/month for 11 months/year. suggests that the use of solar dryers could reduce CO2 emissions compared to other drying systems. [10]

4. Social aspects

Global warming, particularly due to the high level of GHG emissions, poses a significant threat to the world. Governments and industries worldwide have attempted to reduce emissions by switching from fossil fuel-based energy to solar energy. The most popular governments address the issue by establishing energy policies that focus on legislation and international treaties, and the market incentives to investors. Although credits have been suggested to mitigate emissions, it should be noted that energy policies are often country-specific and hence "one-size-fits" type incentives are unlikely to be effective. Some countries promote the use of renewable and clean sources such as solar energy. In 2015, about 19.3% of the global energy consumed was generated from renewable energy sources, with wind, solar, biomass, and geothermal power accounting for about 1.6%. [11]

Conclusion

Drying provides an extended period, reduces transportation prices, and decreases losses for numerous foods, and it is an important aspect of half of the food processing trade across the world. Recent literature is targeted at applying advanced techniques for drying intensification and enhancing standard drying performances with relevant product quality and energy savings. Mixtures of drying methods/hybrid drying and advanced pre-treatments are helpful for optimum results for each product's quality and environmental impact. The right choice of drying strategies and mathematical optimizations (modeling) of the method will cut back on energy consumption, operational prices, and supply superior quality merchandise. However, thermal drying techniques like hot air have adverse effects on shrinkage, colour, and textural properties. However, they're economic. Improving the standard characteristics of dried food has been the subject of many studies on drying and pre-drying methods for the past 20 years. A variety of pre-drying treatments and drying strategies, investigated in numerous foods, have been developed, showing an improvement in quality, higher energy conservation, and higher method potency. Hybrid-drying techniques have shown promising results in the development of dried food product quality, together with each colour and aroma. Despite those technological developments, getting high-quality dried products continues to be difficult as dried area units are sensitive to having completely different pre-drying and drying method conditions, chiefly regarding colour. Moreover, the standard of dried herbs is incredibly sensitive to the kind of food, harvest season, postharvest practices, and storage conditions. Therefore, improvement of quality needs to find out every specific pre-drying and drying methodology for every style of a food product.

References

1) F. Khachik, L. Carvalho, P. S. Bernstein, G. J. Muir, D.-Y. Zhao, and N. B. Katz, “Chemistry, distribution, and metabolism of tomato carotenoids and their impact on human health,” Experimental Biology and Medicine, vol. 227, no. 10, pp. 845–851, 2002.
2) Mujumdar, A.S., 1995, Superheated Steam Drying, pp. 1071-1086, in A.S. Mujumdar (Ed.) Handbook of Industrial Drying, 2nd Edition, Marcel Dekker, New York.
3) Adams, R. L. & Thompson, J. F. (1985). Improving drying uniformity in concurrent flow tunnel dehydrators. Trans. ASAE, 28(3), 890-892.
4) Miss. Shilpa B. Mali1 and Prof. M. C. Butale2; A Review Paper on Different Drying Methods; Vol. 8 Issue 05, May-2019
5) Ian C Kemp Senior Technical Manager, GMS, GlaxoSmithKline plc, Ware, United Kingdom; humidity effects in solids drying processes; ucsf library & ckm on April 21, 2015
6) S. Dhanuskodi, V. H. Wilson, K. Sudhakar, Resource-Efficient Technologies. (2016)
7) 9. S. Faal, T. Tavakoli, B. Ghobadian, Journal Food Science Technology. (2014).
8) A. K. Haghi* and n. Amanifard; analysis of heat and mass transfer during microwave drying of food products; Vol. 25, No. 03, pp. 491 - 501, July - September, 2008
9) Javed Iqbal M, Waseem Akbar M, Rawal Aftab, Ibrar Younas, Umer Jamil;Heat and mass transfer modeling for fruit drying: a review; Volume 7 Issue 3 – 2019

10) Raquel P. F. Guiné; The Drying of Foods and Its Effect on the Physical-Chemical, Sensorial and Nutritional Properties; International Journal of Food Engineering Vol. 4, No. 2, June 2018

11) S. Septiena, *, S.W. Miraraa , B.S.N. Makununikaa , A. Singhb , J. Pocockb , K. Velkushanovaa , C.A. Buckleya; Effect of drying on the physical and chemical properties of faecal sludge for its reuse; Journal of Environmental Chemical Engineering 8 (2020) 103652

12) Dania Awni Al-Said, M.S.; effect of high temperature drying of paper on heat transfer ra tes and sheet properties; 4-2008

13) N. A. Vlachos,1 T. D. Karapantsios,1,2,* A. I. Balouktsis,3 and D. Chassapis3; design and testing of a new solar tray dryer; 20(5), 1239–1267 (2002)

14) Setia Budi Sasongko * , H. Hadiyanto, Mohamad Djaeni, Arninda Mahar Perdanianti, Febiani Dwi Utari; Effects of drying temperature and relative humidity on the quality of dried onion slice; Heliyon 6 (2020) e04338

15) Anna Kaczmareka,*, Maria Wesoáowskaa; Factors affecting humidity conditions of a face wall layer of a heated building; Procedia Engineering 193 (2017) 205 – 210

16) Paula Settea,c, Daniela Salvatoria,c and Carolina Scheborb,c; physical and mechanical properties of raspberries subjected to osmotic dehydration and further dehydration by air- and freeze-drying; http://dx.doi.org/doi:10.1016/j.fbp.2016.06.018

17) Lyes Bennamoun a,n , Patricia Arlabosse b , Angélique Léonard a; Review on fundamental aspect of application of drying process to wastewater sludge; Energy Reviews 28 (2013) 29–43

18) Rosdanelli Hasibuan1, a) and Muhammad Bairuni1, b; Mathematical Modeling of Drying Kinetics of Ginger Slices; AIP Publishing. 978-0-7354-1687-1/$30.00

19) Somboon Wetchacama1, Somchart Soponronnarit1, Somkiat Prachayawarakorn1, Adisak Pongpullponsak1, Wuttitat Tuntiwetsa 2 and Suprarat Kositcharoeankul3; Study of Parameters Affecting Drying Kinetics and Quality of Corns; Kasetsart J. (Nat. Sci.) 35: 195 - 204 (2001)

20) Natalya BUROVA 1; Nadezhda KISLITSINA 2; Faina GRYAZINA 3; Galina PASHKOVA 4; Albert Kuzminykh; A review of techniques for drying food products in vacuum drying plants and methods for quality control of dried samples; Vol. 38 (Nº 52) Year 2017. Page 35

21) A. C. Cruz, R. P. F. Guiné, and J. C. Gonçalves, "Drying kinetics and product quality for convective drying of apples (cvs. Golden Delicious and Granny Smith)," International Journal of Fruit Science, vol. 15, no. 1, pp. 54–78, Jan. 2015.
22) N. Adak, N. Heybeli, and C. Ertekin, "Infrared drying of strawberry," Food Chemistry, vol. 219, pp. 109–116, Mar. 2017.
23) Beaudry C, Raghavan GSV, Ratti C, Rennie TJ (2004) Effect of four drying methods on the quality of osmotically dehydrated cranberries. Drying Technol 22:521–539.
24) Wei, X.; Fan, K.; He, J.; Yan, F. Characterization of thin layer hot air drying of celery root. Adv. J. Food Sci. Technol. 2015, 9, 412–421.
25) Białobrzewski, I. Determination of the heat transfer coefficient by inverse problem formulation during celery root drying. J. Food Eng. 2006, 74, 383–391.
26) Aliba¸s, ˙I. Determination of Vacuum and Air Drying Characteristics of Celeriac Slices. J. Biol. Environ. Sci. 2012.
27) Ježek, D.; Tripalo, B.; Brnci´c, M.; Karlovi´c, D.; Brnˇci´c, S.R.; Viki´c-Topi´c, D.; Karlovi´c, S. Dehydration of celery by infrared drying. ˆ Croat. Chem. Acta 2008.
28) Veli´c, D.; Bili´c, M.; Tomas, S.; Planini´c, M.; Buci´c, A.; Svoboda, Z. The effect of temperatures and pre-treatments on the quality of celery root drying in fluid bed drier the effect of temperatures and pre-treatments on the quality of celery. In Proceedings of the 4th International Conference SIPA'05, Timi¸soara, Romania, 24–26 November 2005; pp. 173–180.
29) Priecina, L.; Karklina, D. Natural Antioxidant Changes in Fresh and Dried Spices and Vegetables. Int. J. Biol. Biomol. Agric. Food Biotechnol. Eng. 2014.
30) Jin, W.; Mujumdar, A.S.; Zhang, M.; Shi, W. Novel Drying Techniques for Spices and Herbs: A Review. Food Eng. Rev. 2018.
31) Akkermans, W.G.M.; Coppenolle, H.; Goos, P. Optimal design of experiments for excipient compatibility studies. Chemom. Intell. Lab. Syst. 2017.
32) Nooraziah, A.; Tiagrajah, V.J. A study on regression model using response surface methodology. Appl. Mech. Mater. 2014.
33) Response Surface. Available online: https://www.statease.com/docs/v11/tutorials/multifactor-rsm/ (accessed on 23 June 2021)
34) Otwell, W.S.; Iyengar, R. Inhibition of Enzymatic Browning in Foods and Beverages. Crit. Rev. Food Sci. Nutr. 1992.

35) Faal, S.; Tavakoli, T.; Ghobadian, B. Mathematical modelling of thin layer hot air drying of apricot with combined heat and power dryer. J. Food Sci. Technol. 2015.
36) Menon, A.; Stojceska, V.; Tassou, S.A. A Systematic Review on the Recent Advances of the Energy Efficiency Improvements in Non-Conventional Food Drying Technologies. Trends Food Sci. Technol. 2020, 100, 67–76.
37) Tontul, I.; Ero ˘glu, E.; Topuz, A. Convective and Refractance Window Drying of Cornelian Cherry Pulp: Effect on Physicochemical Properties. J. Food Process. Eng. 2018, 41, e12917
38) Richardson, P. (Ed.) Thermal Technologies in Food Processing; Woodhead Publishing in Food Science and Technology; CRC Press: Boca Raton, FL, USA; Woodhead: Cambridge, UK, 2001; ISBN 978-1-85573-558-3.
39) Sun, D.-W. Thermal Food Processing: New Technologies and Quality Issues; CRC Press: Boca Raton, FL, USA, 2012; ISBN 978-1-4398-7679-4. 37. Pawar, S.B.; Pratape, V.M. Fundamentals of Infrared Heating and Its Application in Drying of Food Materials: A Review: Mapping of Infrared Drying of Foods. J. Food Process. Eng. 2017, 40, e12308.
40) Krishnamurthy, K.; Khurana, H.K.; Soojin, J.; Irudayaraj, J.; Demirci, A. Infrared Heating in Food Processing: An Overview. Comp. Rev. Food Sci Food Saf. 2008, 7, 2–13.
41) Ortiz-Jerez, M.J.; Ochoa-Martínez, C.I. Heat Transfer Mechanisms in Conductive Hydro-Drying of Pumpkin (Cucurbita maxima) Pieces. Dry. Technol. 2015, 33, 965–972.
42) Nindo, C.I.; Tang, J. Refractance Window Dehydration Technology: A Novel Contact Drying Method. Dry. Technol. 2007, 25, 37–48.
43) Stig Stenstr€om; Drying of paper: A review 2000–2018; https://doi.org/10.1080/07373937.2019.1596949
44) Martina Lindner; Factors affecting the hygroexpansion of paper; J Mater Sci (2018) 53:1–26
45) Piotr Przybylek, Hubert Moranda, Hanna Moscicka-Grzesiak; Analysis of Factors Affecting the Effectiveness of Drying Cellulose Materials with Synthetic Ester; DOI: 10.1109/TDEI.2020.008749
46) Jianhua Zhao1,*, Frank Meissener2, John Grunewald2, Shuo Feng3; Experimental investigation of the drying behaviour of the building materials; E3S Web of Conferences 172, 17002 (2020)

47) Markku Karlsson; DRYING OF PAPER – AN OVERVIEW, THE STATE OF PAPER DRYING KNOWLEDGE; DOI: 10.15376/frc.2001.1.709.

48) Dania Awni Al-Said; Effect of High Temperature Drying of Paper on Heat Transfer Rates and Sheet Properties; 4-2008

49) Donald G. Mercer; An Introduction to the Dehydration and Drying of Fruits and Vegetables; ISBN 978-0-88955-621-8

50) Gail M. Newman,= William E. Price"* & Lawrence A. Woolfb; Effects of temperature upon the kinetics of moisture loss during drying; Food Chemistry, Vol. 57, No. 2, pp. 241-244, 1996

51) CHAPTER-7 DRYING

52) Paper Machine Clothing · Second Edition; Drying

53) Dania alsaid ;effect of high temperature drying of recycle paper on heat transfer rate and sheet properties ;2004

54) Milivoj Radojˇcin 1,*, Ivan Pavkov; Effect of Selected Drying Methods and Emerging Drying Intensification Technologies on the Quality of Dried Fruit:A Review; https://doi.org/10.3390/pr9010132

55) Messaoud Sandali ; Improvement of the Thermal Performance of Solar Drying Systems Using Different Techniques:A Review; doi:10.1115/1.4043613

56) Daniel Maisnam1, Prasad Rasane; Recent advances in conventional drying of foods; Accepted on February 23, 2017

57) Sadat Kamal Amit†, Md. Mezbah Uddin†, Rizwanur Rahman; A review on mechanisms and commercial aspects of food preservation and processing; Amit et al. Agric & Food Secur (2017) 6:51 DOI 10.1186/s40066-017-0130-8

58) Seung Hyun Lee1, Jeong Gil Park1; Drying Characteristics of Agricultural Products under Different Drying Methods: A Review; J. of Biosystems Eng. 41(4):389-395. (2016. 12)https://doi.org/10.5307/JBE.2016.41.4.389