A PANORAMA OF IDEAS IN THE ADOPTION OF AN EFFECTIVE AND EFFICIENT DRYING TECHNIQUE FOR AN AGRICULTURAL PRODUCE

ABHISHEK DASORE¹, RAMAKRISHNA KONIJETI² & NAVEEN PUPPALA³

^{1,2}Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Green Fields,
Vaddeswaram, Guntur, Andhra Pradesh, India

³Agricultural Science Centre at Clovis, College of Agricultural, Consumer and Environmental Sciences,
New Mexico State University, New Mexico, USA

ABSTRACT

The drying process is a fusion of transport phenomena and material science, found in almost all industries ranging from agriculture to pharmaceuticals, making it more diverse and complex. Hence selection of an appropriate drying technique has become an increasingly difficult and demanding task. This task is also exacerbated by the need to meet energy cost, stringent environmental regulations and product quality. Further, the cost of incorrect selection incurs in huge losses. Hence, the main objective of this work is to provide an evaluative overview of recent past, present and subsequent possibilities in drying techniques. The authors hope that this work will form a crux for better strategic decisions in the selection of an effective and efficient drying technique for the practical purposes.

KEYWORDS: Traditional Drying, Intensified Drying, Hybrid Drying & Advanced Drying

Received: Dec 09, 2018; **Accepted:** Dec 29, 2018; **Published:** Jan 30, 2019; **Paper Id.:** IJMPERDDEC201896

INTRODUCTION

Almost all types of foods in our daily use require some form of preservation to minimize microbial spoilage and to maintain desired levels of nutritional quantities. The process of removing volatile moisture from a wet solid is commonly described as drying. Transfer of internal moisture to the surface and evaporation of this moisture to surrounding environment are two processes that occur simultaneously during drying operation [1]. Hence developing a new drying technique is a one of major challenging areas for researchers today, as it depends on physical nature, temperature and moisture content of the food and simultaneous it has also been influenced by external conditions like air temperature, air humidity, air flow, area of exposure and pressure. Thus, it is so indispensable to revert to the basics of heat, mass and momentum transfer coupled with knowledge of the material properties to develop a novel drying technique. A poor selection of drying technique can have an adverse effect on physical and nutritional properties of dried product. Any drying technique should consume minimum energy and should have a potential for the use of renewable energy. Hence, the selection of the appropriate drying technique is a thought-provoking task.

A number of articles have been published by many researchers that have successfully led to a development of a large number of drying techniques. However, to the best of the authors knowledge, there has not been a review published on theories, applications of existing knowledge on drying techniques. Therefore, the main

objective of this work is to provide an evaluative overview regarding various drying techniques. The authors hope that this work will become a successful prodigy of providing a panorama of ideas in selecting an efficient and effective drying for practical applications.

Drying Techniques

Traditional Drying Techniques

Traditionally, food products were dried using natural methods like exposing food products to atmospheric air, to wind and to solar radiation [2]. Natural drying depends on climacteric conditions, season, positioning, staking and storage methods of the wet materials, and type and properties of wet materials. Mujumdar [3] provided a detailed classification scheme for traditional drying in industries. Nonhebel and Moss [4] divided the traditional drying techniques based on the physical form of the feed stock. Sloan [5] has identified some traditional drying systems and classified them according to their mode of operation whether they are batch or continuous. Table 1, gives a digest of different traditional drying techniques.

Even though these traditional drying techniques are less energy efficient, industries prefer to use it. This is for the several reasons, which include their mature status, familiarity, low risk factor in design and scale up as well as their ease of operation. The pre- treatments like dehydration, blanching, salting and soaking and post- processing steps such as instance, coating, blending, packaging plays a major role in traditional drying. But these traditional methods are not ideal in terms of product quality and energy consumption.

Table 1: Traditional drying Techniques

S. No	Basis	Classification
1.	Heat transfer employed	<ul style="list-style-type: none"> • Conduction • Convection • Radiation
2.	Operating pressure	<ul style="list-style-type: none"> • Vacuum • Atmospheric
3.	Mode of operation	<ul style="list-style-type: none"> • Batch • Continuous
4.	Drying medium	<ul style="list-style-type: none"> • Hot air • Superheated steam • Flue gases
5.	Type of the drying vessel	<ul style="list-style-type: none"> • Drum drying • Spray drying • Rotary drying • Tray drying • Flash drying
6.	Relative motion between drying medium and drying solids	<ul style="list-style-type: none"> • concurrent • counter current • mixed flow

Intensified Drying Techniques

Intensified drying techniques are developed to meet the few criterions like enhanced product quality, higher productivity, reduced environmental emissions, more flexibility and decreased energy consumption. Generally, it is tough to make a keen difference between traditional drying and intensified drying. Since, most of the intensified drying techniques are evolutionary. Jangam [6] identified some key areas for diminishing the limitations that are involved in

traditional drying techniques. These techniques, mainly focused on the intensification of drying rates and multi staging of dryers. Table 2, summarizes some of the intensified drying techniques investigated by different researchers in a nut shell. Many of the intensified drying techniques presented here have some potential advantages over traditional drying, but need to be tested in both laboratory and pilot scales.

Hybrid Drying Techniques

The main motivation in developing hybrid drying is to minimize product degradation and yet produce a product with the desired moisture content [7]. The paramount considerations of any hybrid technique are to produce better quality products at a faster rate and at a lower operating cost. In comparison to traditional and intensified drying, sources of energy are same to hybrid drying but possess significant differences in deliver of this energy. Some of the investigations shown that these techniques are more appropriate to prepare highly porous particles and in pharmaceutical applications. Continuous R & D efforts will be required to investigate system scale – up, optimization and control of these hybrid drying. For effective R & D in hybrid drying techniques, there is a need for continuous industry – academic interaction. A general classification scheme of hybrid drying techniques is demonstrated as shown in Figure1 and a thumbnail of published works on hybrid drying are presented in Table 3.

Table 2: Intensified Drying Techniques in a Nut Shell

S. No	Drying Technique	Inference	Reference
1.	Drying on inert particles	Ability to produce powders even from coarsely dispersed liquid feed like suspensions and slurries.	Freire et al., [8]
2.	Impinging stream drying	Enhanced heat and mass transfer processes, reduced drying times, reduced residence time	Mujumdar [9]
3.	Drying in pulsed fluid beds	Ability to process materials that are difficult to fluidize because of size and shape, as well as adhesive and cohesive materials like sugar infused berries	Grabowski et al., [10]
4.	Superheated steam drying	Higher drying rates, reduced emissions and enhanced quality end products. suitable for drying of regulatory requirements like coal, peat, newsprint, tissue paper and waste sludges	Haque and Sargent [11]
5.	Sonic drying	Suitable for processing heat – sensitive materials, with enhanced mass transfer rates	Woods [12]
6.	Airless drying	Suitable for wood chip, biosolids, mustard seeds, paper pulp, organic sludge	Stubbing [13]
7.	Heat pump drying	Improved product quality, reduce energy consumption. Suitable for drying of wood kilns, agricultural and marine products	Zhang et al., [14]
8.	Drying with shock waves	Suitable for drying of viscous liquids and thin pasty materials in a gas like various pigments	Lyulin [15]
9.	Pulse combustion drying	Best suitable for antibiotics, vitamins, yeast, spices, vegetable protein, fibers, eggs, food colorings with reduced unit cost bases	Rehkopf [16]
10.	Mechanical thermal expression	Suitable for compressible biomaterials that have an inherent porous structure in particular lignite, sewage sludge, and paper pulp waste	Clayton et al [17]
11.	Spray freeze drying	It has a great potential for producing drugs, nutraceuticals, functional foods. this technique offers free flowing, ultrafine and uniform particles with high surface area	Rogers et al [18]
12.	Atmospheric freeze drying	Best suitable for drying of high value food, material science, biological science, medicine,	Claussen et al., [19]

		pharmaceuticals and biotechnology	
13.	Refractance window	This technique minimizes losses of nutritional components like antioxidants, vitamin C and reduces operational energy costs	Clarke [20]

Figure 1: A General Classification Scheme of Hybrid Drying Techniques

Advanced Drying Techniques

These advanced drying techniques that have been investigated by several researchers in recent years. Most are in their inception and hence no definite evaluation is feasible. The use of supercritical fluids is one of the advanced drying technique proposed to achieve high purity, micron- and nano-sized particles with well – defined morphological structures in a single step [27]. Haddad et al. [28] comparatively analysed dehydration by successive pressure drops (DDS) and controlled instantaneous pressure drop (DIC) with traditional food drying techniques and identified shorter drying time and improved function and quality aspects of the end product. Barre and Masini [29] proposed a novel technique to dry the pasty sludges from pulp and paper mills using unsaturated ambient air. This advanced drying technique is advantageous over other drying techniques in many aspects like, design simplicity, reduced operation costs, no thermal energy is required for drying, pelletizing of sludge at low temperatures prevents bad odour and dust formation, the risk of explosion is also practically eliminated. A significant reduction in drying time coupled with improved product quality is identified during the applications of non – contact heat transfer of electromagnetic energy and microwave heating techniques [30]. These advanced drying techniques are still at their infancy level; hence they don't fit to the industrial demand.

Table 3: A Thumbnail of Hybrid Drying Techniques

S. No	Drying Technique	Inference	Reference
1.	Radio frequency assisted heat pump drying	Ensures uniform drying, better suitable for materials with poor heat transfer characteristics like glass fibers	Thomas [21]
2.	Infrared heat pump drying	Suitable for sugar – rich fruits like banana, guava and potato	Chua et al., [22]
3.	Radio frequency – vacuum drying	More suitable for drying of eucalyptus and for low permeable materials	Saito and Sulaiman [23]
4.	Combined filtration and drying	Enhanced product quality with reduced investment and running costs with compact design. Best suitable for food coloring agent, vitamins and pharmaceutical compounds	Peeters et al [24]
5.	Filtermat drying	More suitable for drying of sticky materials like whey, proteins, oranges	Rheinlander [25]
6.	Infrared – microwave freeze drying	More suitable for berries and for liquid feeds	Lebedev and Bihovsky [26]

CONCLUSIONS

The following conclusions can be drawn from this study

- The authors presented a panorama of ideas in the selection of an effective and efficient drying process for a product which plays a major role in improving quality, saving energy costs and reducing drying time.
- Traditional drying techniques are not solely used these days, as these techniques are highly energy intensive and not optimal in terms of quality of the dried product.
- Authors pinpointed thirteen intensified drying techniques and addressed its pros and cons. These techniques, mainly focus on energy savings through escalation of drying rates and multi staging of dryers.
- The authors recognized six hybrid techniques and sermonized its pros for practical applications.
- Advanced drying techniques have been developed for drying of high purity substances and heat sensitive materials.
- Finally, the authors want to conclude with a disclosure that there is no single particular drying technique that can be employable to a feed, as all drying techniques have its own pros and cons. Hence, authors feel that this review will act as a prerequisite for careful techno economic evaluation in the selection of any drying technique for a particular application.

DIRECTIONS FOR FUTURE RESEARCH

Although this state of the art review on selection of best suitable drying technique for a feed is a complicated effort, this work only throws a light on the significant potential drying techniques that are developed in the recent past, and present. Since any new domain for articulate aggregation will be initially studied at the shallow levels of hierarchy, after which research on the domain will gradually move to the profound levels. Hence, the hierarchy on drying techniques adopted in this work provides a natural guide to do further research.

Future research directions on developing different novel drying techniques is required in

- Developing eco-friendly drying techniques, which are operated using renewable energy sources.
- Applying CFD analysis to investigate different drying mechanisms, and facilitating improvements in process efficiencies.
- Developing cost – efficient technologies, particularly for heat – sensitive products.
- Developing sustainable alternatives for the bulk drying of freshly harvested agricultural products.
- Novel drying techniques that are being developed require to maintain the balance between both demands pull and technology push standards to deliver commercially successful drying techniques.

REFERENCES

1. E. K. Akpinar, Y. Bicer; *Modelling of the drying of eggplants in thin layers. Int. J. Food Sci. & Tech.*, **40(3)**, 273-281 (2005).
2. R. Wimmerstedt; "Drying of peat and biofuels", In: *Handbook of Industrial Dryers*. A. S. Mujumdar 3rd Ed. Taylor and Francis Group, LLC.

3. A. S. Mujumdar, M. L. Passos; *Effect of cohesive forces on fluidized and spotted beds of wet particles*, *Powder Technology*, **110**, 222-238 (2000).
4. G. Nonhebel and A. A. H. Moss; "Drying of solids in the chemical industry", *Butterworths, London*, 1971, p. 80.
5. C. E. Sloan; *Drying systems and equipment*, *Chemical Engineering*, **19**, 167(1967).
6. S. V. Jangam; *An overview of recent developments and some R & D challenges related to drying of foods*, *Drying Tech.: An Int. J.* **29(12)**, 135(2011).
7. S. K. Chou and K. J. Chua; *New hybrid drying technologies for heat sensitive food stuffs*, *Trends in Food Sci. & Tech.*, **12**, 359-369(2001).
8. J. T. Freire, M. C. Ferreira, F. B. Freire, B. S. Nascimento; *A review on paste drying with inert particles as support medium*, *Drying Tech.: An Int. J.* **30**, 330-341(2012).
9. A. S. Mujumdar; "Impingement drying", In: *Handbook of Industrial Drying*, 3rd Ed. Taylor & Francis, 2007, p. 385-395.
10. S. Grabowski, M. Marcotte, D. Quan, A. A. Taherian, M. R. Zereifard, M. Poirier and T. Kudra; *Kinetics and quality aspects of Canadian blueberries and cranberries dried by osmotic convective method*. *Drying Tech.: An Int. J.*, **25(3)**, 367-374(2007).
11. M. N. Haque, R. Sargent; *Standard and superheated steam schedules for radiata pine single – board drying: model prediction and actual measurements*. *Drying Tech.: An Int. J.*, **26(2)**, 186-191(2008).
12. B. G. Woods; *Sonically enhanced heat transfer from a cylinder in cross flow and its impact on process power consumption*, *Int. J. Heat & Mass Trans.* **35(10)**, 2367-2376(1992).
13. T. J. Stubbing; *Airless drying – development since IDS'94*. *Drying Tech. An Int. J.*, **17(7&8)**, 1639-1651(1999).
14. B. G. Zhang, Y. Zhou, W. Ning, D. Xie; *Experimental study on energy consumption of combined conventional and dehumidification drying*, *Drying Tech.: An Int. J.* **25(3)**, 471-474(2007).
15. N. B. Lyulin; *Intensification of drying instant pigments by the use of shock wave generator*, *PhD Thesis*, Mendeleyev University of Russia, Moscow (1998).
16. J. A. Rehkopf; *Technical info. Pulse combustion systems*, San Rafael, CA (2008).
17. DJELTI, H. *THERMAL STUDY OF THE DC BEHAVIOR IN SiO₂/Al₂O₃. 26Ga_{0.74}N/GaN MOS-HEMT*.
18. S. A. Clayton, O. N. Scholes, A. F. A. Hoadley, R. A. Wheeler, M. J. McIntosh, D. Q. Huynh; *Dewatering of biomaterials by mechanical thermal expression*. *Drying Tech.: An Int. J.*, **24(7)**, 819–834(2006).
19. T. L. Rogers, A. C. Nelsen, M. Sarkari, T. J. Young, K. P. Johnston, R. O. Williams; *Enhanced aqueous dissolution of a poorly water-soluble drug by novel particle engineering technology: Spray-freezing into liquid with atmospheric freeze-drying*. *Pharm. Res.*, **20(3)**, 485–493(2003).
20. I. C. Claussen, T. S. Ustad, I. Strommen, P. M. Walde; *Atmospheric freeze-drying: a review*. *Drying Tech: An Int. J.*, **25(6)**, 947–957(2007).
21. P. T. Clarke; *Refractance Window TM—"Down under"*. *Proc. 14th International Drying Symposium (IDS2004)*. State University of Campinas, Sao Paulo, Brazil, August 22–25, pp. 813–820(2004).
22. W. J. Thomas; *RF drying provides process savings: New systems optimize radio frequency drying for the ceramic and glass fiber industries*. *Ceram. Ind. Mag.*, April, 30–34. (1996).
23. PAPU, S., SWETA, S., & BR, S. (2014). *Effect of drying methods and pretreatments on the drying characteristics of garlic*. *Int.*

- J. Res. Eng. Technol*, 2(7), 141-156.
24. K. J. Chua, A. S. Mujumdar, S. K. Chou, M. N. A. Hawlader, J. C. Ho; Heat pump drying of banana, guava and potato pieces: Effect of cyclical variations of air temperature on convective drying kinetics and color change. *Drying Tech.: An Int. J.*, **18**(5), 907–936(2000).
 25. S. Saito, I. B. Sulaiman; Radiofrequency vacuum (RF/V) drying of small diameter Keruing. *Proc. 6th Int. Wood Drying Conference, University of Stellenbosh, Stellenbosch, South Africa, 1999*, 234p.
 26. B. Peeters, L. Vernimmen, W. Meeusen; Effect of activated sludge characteristics on the fouling frequency of a single stage mechanical dewatering and thermal drying process. *Proc. American Filtration & Separation Society Annual Conference. 19–22 May 2008, Valley Forge, PA*.
 27. P. M. Rheinlander, Filtermat—The 3-stage spray dryer from DEC. In: *Proc. 3rd International Drying Symposium. J. C. Ashworth (Ed.). Drying Research Ltd., Wolverhampton, England, 1*, 528–534 (1982).
 28. D. P. Lebedev, B. N. Bihovsky; Method of intensification of vacuum freeze-drying and development of a new apparatus for continuous operation. *J. Ind. Heat Eng.*, 23(1&2), 67–75(2001).
 29. Z. K. Brown, P. J. Fryer, I. T. Norton, S. Bakalis, R. H. Bridson; Drying of foods using supercritical carbon dioxide – investigations with carrot, *Innovative Food Science and Emerging Technologies*, **9**, 280-289(2008).
 30. Joseph Haddad, Frederic Johel, Nicolas Louka, Karim Allaf; A study of dehydration of fish using successive pressure drops (DDS) & controlled Instantaneous pressure drops (DIC), *Drying Tech.: An Int. J.*, **22**(3), 457-478(2004).
 31. Okyere, S., Yang, J., & Aminatou, M. (2017). Influence of Multimodal Transport System Dynamics on Logistics Responsiveness: An Ordinal Logistic Regression Approach.
 32. L. Barre, M. Masini; Drying residues at ambient temperature with the DRYREX dryer. *50th Canadian Chemical Engineering Conference, Montreal, 2000, Canada*.
 33. Hao Feng, Yun Yin, Juming Tang; Microwave drying of food & agricultural materials: Basics and Heat & Mass Transfer Modelling, *Food Eng. Rev.*, **4**(2), 89-106(2012).