Chapter 1

Introductory Chapter: Principles of Sustainable Drying

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Additional information is available at the end of the chapter

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1. Historical background

Currently in many industrial processes, removal of water or residues of different finished products can pose a serious technical, economic and environmental problem. To solve this, the unit operation of "Drying" is employed. This operation is the world's oldest method for preserving food, elaborating building material, producing pigment and drying animal skins.

In the past centuries, people in the near East kept fruits by wrapping them in dried palm leaves and burying them in hot sand to dry. Moreover, people in the Arctic made deposits with the surplus of walrus meat, "freeze dried" it by piling up stones away from their home to avoid predators from devouring it. Native Americans in the northern parts of the United States had employed the smoke from fire for drying meat, herbs, vegetables or fish through recirculation of hot air.

For many years, the Indians in Peru dried potatoes with a simple but effective process. In the first place, the material was frozen all night outdoors and the next day, the potatoes were fast thawed, with that the moisture content remaining in the material boiled down. Then, they air-dried the potatoes until crisp enough to be stored. Almost everywhere in the world, people have utilised different food-drying methods in order to save food from one season to the next, be it grains, meat, fruits, or herbs among others.

Over time, people in different cultures perfected drying wild and cultivated foods. For example, The Greeks and Romans dried peas and grapes successfully. The Persians learned how to preserve apricots and melons. The Chinese and Japanese were clever at the art of food preservation, cured fish and sea vegetables. Mongolian explorers, en route to Europe, packed bundles of dried milk products to sustain them on their long journey [1].

Across time, the process of drying fish and meat has supplied for many people around the world the proteins necessary to live. In other times, the ancestors dried foods and conserved

these for years and years, without the advantage of refrigeration. In fact, the most commonly dried foods were different fish and meat. Ironically the fish is one type of food most difficult to dry, because of its ease for sheltering bacteria in the products without treatment.

Ancestrally, different meats like fishes were treated with curing salt or a brine solution, which helps remove water out of the meat. Finally, fish and meats were treated with smoke for a smoking process [1].

2. Basic theory of drying

The efficient employment of energy in the drying process, the reduction in cost and the minimum impact on the environment are aspects enormously lucrative for the industry. Accordingly, recently a considerable number of reports have been developed around the theme of sustainable drying in both industrial and academic areas. Sustainable drying is intrinsically a multidisciplinary field, which has a very extensive demand in areas such as agriculture, chemical, food, textile, building, tannery and other applications. For understanding this, an optimal knowledge of the three phenomena of transport and suitable knowledge of science of materials are required, because the principal priority is not solely to conserve the energy but, furthermore, to achieve a better product quality through a sustainable drying process [2].

Sometimes it is necessary that products meet some specific requirements after the drying process, like size of the product, free movement or dust free, resistance, particle size distribution, solubility or preservation of active component. As a result, the selection of an adequate process of drying and the design of dryer has a big influence over the quality, shape, size and moisture content of the final product [3].

Because of these, sustainable drying has been a significant part of research since the decade of 1980s. Many studies about sustainable drying generally have two important components: one is the *drying theory*, which treats the analysis of the three phenomenon of transport, and the other one, the *drying equipment,* which has the objectives to design, optimise and fabricate dryers based on the last theory. The drying phenomenon can be defined as a simultaneous process of transfer in momentum, heat and mass, where the end result is the elimination of humidity from the desired products to reduce the water content in them [4].

It is well known that the drying takes place principally through two mechanisms: the movement of humidity from the interior of a material to the outside and the evaporation of humidity from the hot surface of a material to the surrounding. The transport of water are intimately related to some external factors like humidity, pressure, the nature and type of the exposed surface, temperature, and flow velocity [5–7].

Due to its complexity, the investigations on drying are still an area of interest to numerous researchers all over the world. The principal motivation in many of these projects of research in drying is to define the influence of the external factors over the process. The understanding of the drying process with all detail is needed for the design precise of equipment employed

scientific principles, maintaining the quality of the product and energy optimization, but overall from a viewpoint sustainable [8–11].

Despite the increase in the number of studies and technological developments, drying process is nowadays an exclusive area to be studied in detail and extensively by technicians and researchers. It is necessary maintain efforts to make the drying process be more clear for all the people; however, this is a complicated physical phenomenon and is not easy to establish the design and control of the equipment and support the product quality. The employ of knowledge in thermodynamics and transport phenomena for the description of equilibria and kinetics drying is between the modern challenges for the research in this field [12].

3. Classification of drying methods and equipment

In general, the drying methods have been arranged and diversified according to the specific necessities of each product. The drying process takes place in different forms and employs diverse types of equipment, depending on the requirements stipulated by the consumer. As seen in **Table 1**, the equipment for drying can be operated fundamentally with two big modes, which are commonly designated as continuous and batch, depending on operation type.

Though the procedure in continuous is most technical and practicable, the dryers in batch are most commonly employed, especially when the control of quality or considerations of health are important factors. This class of process is seen in the pharmaceutical and food industries [12].

The drying in batch is a chemical process and usually preferred when different materials are handled in the same unit of drying, or when the drying is extensive and difficult and in which batch system is placed downstream and upstream, for example, dried wood, brick, among others. The principal difficulty of a system in batch is that the development does not reach a steady state and this causes continuous changes in the operative function [13].

In contrast, a continuous system needs less work, space and energy. This guarantees a supplementary uniformity in the dried product at an inferior cost than a batch system of identical capacity. Sustainable drying has many forms depending on specifications in the products and the use of various types of equipment. Depending on the type of heat applied, drying system involves two basic methods: non-adiabatic and adiabatic. The heat of vaporisation is supplied by the sensible heat in contact with the material to be dried in the adiabatic processes, whereas in non-adiabatic system, evaporation heat is proportionate only by radiant heat or by heat transported through the walls in interaction with the product [12].

The heat applied during the drying can be studied in four different types: convective, radiative, conductive and dielectric. In the process where heat is applied by conductive, heat transfer proceeds if there exists a gradient of temperature in a solid and necessary heat is acquired from a heat source like an electric heater. Usually, direct contact takes place between the heat generator and the target tissues. The heated gas is dispersed into the dryer by means of a fan for help the drying process through evaporation. The word convection is used to describe the

transfer of heat energy from some gas or air to liquid, solid or gas. The acquired heat in the gas stream is occupied to evaporate humidity from a surface. The phase used for eliminating the evaporated humidity also makes use of gas stream as a transport.

Judgement	Categorization
Type of operation	Batch Continuous
Type of heat applied	Radiation Convection Conduction Intermittent, continuous dielectric Adiabatic or non-adiabatic
Movement of the material in dryer	Moving Stationary Dispersed Agitated
Pressure of operating	Atmospheric Vacuum
Medium of drying	Air Combustible gases Superheated stream
Temperature of drying	Under boiling temperature Over boiling temperature Lower freezing point
Movement between medium and solids	Mixed flow Counter current Co-flowing
Stages employed	Multiples stages Single stage
Time of residence	Long Medium Short

Table 1. Categorization of drying methods and equipment [3, 12].

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