MECHANICAL ENGINEERING ASPECTS FOR FOOD'S LYOPHILIZATION TECHNOLOGY

Drd.eng. Gabriela ANGHEL, Prof.univ.dr.eng. Dumitru MNERIE, Prof.univ.dr.eng. Dumitru TUCU
"POLITEHNICA" University of Timisoara, Center for Research for Integrated Engineering,
gabriela.A@k.ro, dmnerie@mec.utt.ro, dtucu@mec.utt.ro

Abstract:
Mechanical engineering aspects for food's lyophilization technology are very important. Lyophilization is carried out using a simple principle of physics called sublimation. The paper shows some considerations about the process, some important mechanical engineering elements and some consideration about the materials good for trays.

1. INTRODUCTION

The lyophilization process, also known as freeze-drying or sublimation, has many advantages over other processing methods. Since freeze-drying is achieved at lower pressures and temperatures than other methods, it is an inherently gentle process. An oversimplified definition of lyophilization is that it is a means of drying, achieved by freezing the wet substance and causing the ice to sublime directly to vapor by exposing it to a low partial pressure of water vapor. In practice the substance may not be completely frozen, especially if no aqueous solutions are present, and most lyophilization processes are completed by a period of desorption drying.

2. ABOUT LYOPHILIZATION PROCESS

There is no real invention of a freeze-dryer. It appears to have evolved with time from a laboratory instrument that was referred to by Benedict and Manning (1905) as a "chemical pump". Shackell took the basic design of Benedict and Manning and used an electrically driven vacuum pump instead of the displacement of the air with ethyl ether to produce the necessary vacuum. It was Shackell who first realized that the material had to be frozen before commencing the drying process - hence freeze-drying. The literature does not readily reveal the person who first called the equipment used to conduct this form of drying a "freeze-dryer".

The ancient Peruvian Incas of the Andes knew the basic process of freeze-drying food. Freeze-drying, or lyophilization, is the sublimation/removal of water content from frozen food.

The technology of lyophilization appear as a relatively simple process but as the practitioner soon learns the process is deceptively complex and, as a result, is often treated as an art rather than a science. Lyophilization is a process, which extracts the water from foods and other products so that the foods or products remain stable and are easier to store at room temperature (ambient air temperature).

There is two major factors that determine what phase (solid, liquid or gas) a substance will take: heat and atmospheric pressure. For a substance to take any particular phase, the temperature and pressure must be within a certain range. Without these conditions, that phase of the substance can't exist.

Lyophilization is carried out using a simple principle of physics called sublimation. Sublimation is the transition of a substance from the solid to the vapor state, without first passing through an intermediate liquid phase.

To extract water from foods, the process of lyophilization consists of:

- Freezing the food so that the water in the food become ice;
- Under a vacuum, sublimating the ice directly into water vapor;
- Drawing off the water vapor;
- Once the ice is sublimated, the foods are freeze-dried and can be removed from the machine.

3. MECHANICAL ENGINEERING ELEMENTS

The most important mechanical engineering elements are listed below:

- Separated drying chamber and ice condenser to reduce cross-contamination
- Provision of an isolation valve between chamber and ice condenser to allow for end-point determination and simultaneous loading and defrosting
- Construction of the chamber and ice condenser as pressure valves to allow for steam sterilization at 121^0C or higher
- Cooling and heating of the product -support shelves by a circulating intermediate heat-exchange fluid to give even and accurate temperature
- Additional instruments to control, monitor, and record process variables
- Movable product-support shelves to close the slotted bungs used in vials and to facilitate cleaning and loading

Automatic control system with safety interlocks and alarms, duplicated vacuum pumps, refrigeration systems, and other moving parts to enable drying to proceed without endangering the product in the event of mechanical breakdown.

Advances in freeze drying equipment, such as automatic loading, has to some degree reduced the need for the use of a tray. But this is only for products that are contained in vials or bottles and these advance systems are generally not used to freeze dry bulk materials. So for bulk products, we still must rely on a large container that we generally classify as a tray. We will certainly point out the advantages, disadvantages and perhaps pose some new questions that we need to address. The trays will be considered range from the traditional metal (stainless steel) to the more recently introduced.

Trays are generally constructed out of three basic materials: metal, glass and plastic. As a result of the composition, each material will offer its own unique advantage and disadvantage. The trays can be making from:

- Cold Roll Steel used in the manufacture of flowers. If its are either galvanized or electroplated especially it would be easier to construct and may represent the least expensive of all the trays.

- Stainless Steel is most commonly used trays in the lyophilization or freeze-drying of products, because that is corrosion resistant, can be depyrogenated at temperatures of 250^oC, are durable, require no special handling, are reusable which in time can off-set their initial higher cost.

- Aluminum trays are used in the freeze-drying of bulk materials. They are certainly lightweight when compared to the cold roll and stainless steel trays and are corrosion resistance. In addition, its can be anodized to give them a black surface, which will increase their emissivity aid somewhat to the energy transfer resulting from radiant energy. Also its can be steam sterilized. Because aluminum is a relatively soft metal, one must be concerned with the effects of “galling” (the removal of a surface layer generally in the form of a dust) should the product have to be removed by scraping.

- Glass is good for all bulk products that can be lyophilized or freeze-dried come into contact with a metal surface. As a result of their composition, these trays have similar advantages as those constructed from stainless steel, except they are by their very nature fragile and are subject to breakage that may occur over time from stress strains resulting from age and thermal shock.

- Plastic Trays can be used in some applications which not requiring high temperature depyrogenation. It tends to be lightweight when compared to the trays made from the previous materials and easy to clean and quite durable and reusable.

While these trays can also be generally classified as plastic trays, they do have unique features and we felt they deserved their own category in this discussion. The basic reason being that they are covered with a membrane barrier that will allow a formulation prepared in an aseptic environment to be safely lyophilized or freeze dried in a non aseptic environment. This feature is of major importance to those working with small freeze dryers, which were not designed to withstand the harsh rigors of steam sterilization. However, given such an advantage there are also some disadvantages in that they tend not to be reusable and as a result of their unique feature to be more costly than those trays fabricate from the above materials.

4. HEAT TRANSFER PROPERTIES

It can consider the role of composition and configuration of the tray can have on the heat transfer properties. For analyse on put the conditions:

- All the trays have the same general rectangular configuration and the only variables will be their total mass and thickness of bottom and walls.
- That all trays contain the same volume of water.
- In each case, the shelf-surface temperature is uniform and chamber pressures are equal.

The heat transfer rate (Q_S) from shelf through the bottom wall of the tray is given by the Fourier`s law:

$$Q_1 = -A\lambda \frac{\partial T}{\partial l} \tag{1}$$

Since the heating or cooling takes place in an unsteady state, the amount of heat (Q) will be:

$$Q = -A\lambda \frac{\partial T}{\partial l} t \tag{2}$$

In the case of the bottom of the tray, the relation (2) becomes:

$$Q_S = A\lambda \frac{(T_s - T_p)}{\delta} \tag{3}$$

Where:

A is the total surface area of the tray, m^2;

$$\frac{\partial T}{\partial l} = \frac{T_s - T_p}{\delta}$$ - the thermal gradient, $^0C/m$, or Kelvin/m

- ? - the thickness of the bottom of the tray, m;
- T_s - the temperature of the shelf surface, given in ^0C;
- T_p - the temperature of the internal bottom surface of the tray, ^0C;
- t - time, sec.

Neglecting the contact resistance between shelf and tray, the external surface temperature of the bottom of the tray is equal to that of the shelf.

One can consider that the temperature gradient has a single direction, perpendicular on the surface of the bottom of the tray. In the regions with a good contact area of the bottom of the tray with shelf surface there is also a good heat transfer. In the regions where the contact is not perfect it appears a new thermal impedance to heat transfer between shelf and bottom of the tray.

5. CONCLUSIONS

Freeze-drying process is not widely used in the food industry due to its high operation cost. Although new improvements such as adsorption, fluidisation, and microwaves have been researched in the last decade in order to reduce costs, vacuum freeze-drying is, up to now, the only technology used in an industrial scale to dry coffee, spices, meats, food ingredients and other high-value foods. However, with the increasing concern about food quality, this process could be considered as a valuable alternative to preserve other foods.

BIBLIOGRAPHY

[1]. Anghel Gabriela, Teleki L., Mnerie D., Tucu D., 1998. Non-conventional mechanical aspects about lyophilization systems, International Conference in Non-conventional technologies, CITN'97; Review of Non-conventional Technologies, no.1/1998; Ed. Augusta, Timisoara, pg. 86-87; ISSN – 1454-3087.
[2]. Fontaine, J. and Ratti, C., 1999. Lumped-parameter approach for prediction of drying kinetics in foods. *Journal of Food Process Engineering* 22 4, pg. 287–305.
[3]. Jennings, T.A., Bacaoanu, A., 2003. Discussion of Lyophilization or Freeze Drying in Trays, Insight journal, Volume 6, no. 5, may 2003.
[4]. Karmas, R., Buera, M.P. and Karel, M., 1992. Effect of glass transition on rates of no enzymatic browning in food systems. *Journal of Agriculture Food Chemistry* 40, pp. 873–879.
[5]. Krokida, M.K. and Maroulis, Z.B., 1997. Effect of drying method on shrinkage and porosity. *Drying Technology* 15 10, pg. 2441–2458.
[6]. Mnerie D., Szendrey R., Teleki L. Tehnologii neconventionale de uscare rapida a materialelor sensibile, International Conference in Non-conventional technologies, CITN-2000, vol.1, Brasov, 2-3 November, 2000, Editure PRINTECH Bucharest, ISBN 973-634-2, pg.229-232.
[7]. Mnerie D., Teleki L. Integrated engineering elements applied for obtain foods preserved by drying, International Conference on Integrated Engineering, C21 2002, 25-26 April 2002, Timisoara, Editure Politehnica, Timisoara, 2002, ISBN 973-8247-92-6, pg.163-164.