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ABOUT QUALITATIVE APPROACH OF MOROCCAN STRAWBERRIES USING FREEZING PROCESS

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ABSTRACT
This paper present the modelling approach of freezing process with an application to Moroccan strawberries. Moroccan strawberries as *Caramosa Chandler* variety, were frozen by two freezing methods: combined (cryogenic-mechanical) and mechanical method. The materials were stored for 10, 20 and 30 days, at –19°C with 2°C of tolerance. The results indicated that mixed cryogenic- mechanical freezing was carried out at –12°C in 19 min, while mechanical freezing was carried out at –18°C in 154 min. There were no significant differences in the texture and chemical properties between the freezing samples, although differences between fresh and frozen strawberries were observed. Evidence indicates that the freezing mixed process with CO2 and mechanical has no significant detrimental effect on nutritive value. It was concluded that this method is better than the mechanical, for this kind of products since there is a considerable time and energy saving.

KEY WORDS
modelling, strawberries, mechanical, cryogenic, freezing, Morocco

1. INTRODUCTION

The application of freezing for the preservation of foods has been practiced for several years to maintain their quality during storage, distribution and marketing. The overall freezing process applied to food consists of three processes: the actual freezing operation, where most of the water in the food is converted into ice, resulting in a hard solid material; frozen storage; and thawing, where the frozen food is more or less transformed back into its original state. Most physical and chemical changes occuring in foods during freezing are caused either directly or indirectly from water to ice transformations. After modelling freezing and thawing process we expose the results of some application freezing to some moroccan common food as strawberries.

2. THEORICAL APPROACH

2.1. DESCRIBING FREEZING AND THAWING

Heating or cooling of a food product is primarily an unsteady state conduction heat transfer phenomena. Food freezing may be considered as an extension of the conduction problem, with phase change of the water to ice or vice versa occurring simultaneously with the heat transfer process. Figure 1 shows one dimensional conduction through a material. If in a certain segment of the material having a thickness of Δx and area cross sectional area A, heat flux q_+ enters from one side and q_- exits from the other side. Then the heat gained per unit mass of the segment (change in enthalpy, H) in incremental time Δt is given by equation 1.

$$A\Delta x\,\Delta H(T)\rho = A\Delta t\left(q_+ - q_-\right) \tag{1}$$

where ρ is the material density, hence

$$\rho\frac{\partial H(T)}{\Delta t} = \frac{\left(q_+ - q_-\right)}{\Delta x} \tag{2}$$

The difference equation 2 in differential yields

$$\rho\frac{\partial H(T)}{\partial t} = \frac{\partial q}{\partial x} \tag{3}$$

Using the definition of heat flux in one dimension, equation 3 can take the following expression:

$$\rho\frac{\partial H(T)}{\partial t} = \frac{\partial}{\partial x}\left[k(T)\frac{\partial T}{\partial x}\right] \tag{4}$$

Using similar arguments, heat transfer equations for a general three dimensional case can be written as:

$$\rho\frac{\partial H(T)}{\partial t} = \nabla.\left(k(T)\nabla.T\right) \tag{5}$$

In most conduction problems the above equation is simplified using the relationship given in equations 6 and 7 to the form described in equation 8 [1]

$$\frac{\partial H(T)}{\partial T} = C_p(T) \tag{6}$$

$$\frac{\partial H(T)}{\partial t} = \frac{\partial H(T)}{\partial T}\frac{\partial T}{\partial t} = C_p(T)\frac{\partial T}{\partial t} \tag{7}$$

$$\rho C_p(T)\frac{\partial T}{\partial t} = \nabla.\left(k(T)\nabla.T\right) \tag{8}$$

However such simplification in the case of freezing of biological materials has certain limitations. For materials density (ρ) and specific heat (c_p) are temperature dependent thermal properties and specific heat has an inherent discontinuity at the freezing point of the product (figure 2). The physiochemical reason behind this discontinuity in specific heat has been discussed by various authors [2] [3]. Hence the enthalpy formulation (equation 4) is popular in determining numerical solutions to the freezing and problems [4] [5][6].

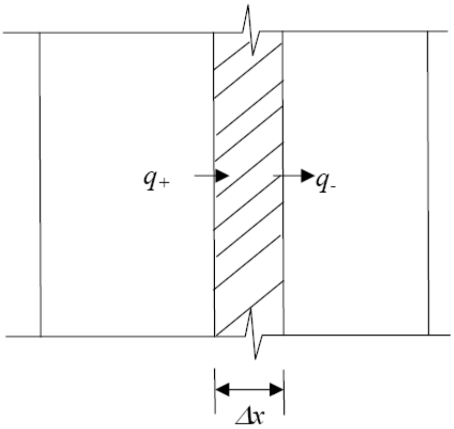

Figure 1 : heat transfer in case of one dimensional geometry

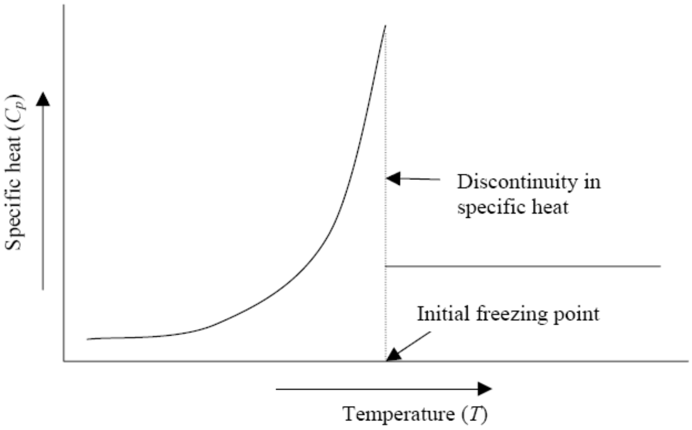

Figure 2. specific heat variation with temperature for biological materials

The enthalpy based differential equation for freezing (equation 4) is non linear in nature since thermal properties (enthalpy, density and thermal conductivity) are functions of temperature (T) and hence that of time (t). Due to this inherent non-linearity, analytical solutions are difficult to obtain. Hence, the enthalpy formulation of the freezing requires numerical solution. If appropriate boundary conditions are known, the differential equations can then be solved by available numerical techniques.

2.2. BOUNDARY CONDITIONS

The boundary conditions that are most commonly encountered in cases of food freezing or thawing are: temperature boundaries, convective boundaries or flux boundaries. For example in a case of freezing of a one dimensional slab shaped object in a contact freezer the product is subjected to constant temperature boundaries on either side. In case of blast freezing, immersion freezing, impingement freezing and other freezing operations with flow around the product, the product is subjected to a convective heat transfer boundary.

In cases such as radiation thawing, a constant flux boundary is observed. For successful numerical simulation of a freezing or thawing process it is important to mathematically describe these boundary conditions. As an example we consider a one dimensional slab undergoing freezing or thawing (figure 3). The two sides of the slab can be subjected to three different boundary conditions as described by equations 9, 10 and 11. If the boundaries are subjected to a constant temperature T_s (eg. in a plate freezer) then they can be defined as:

$$T(X,t) = T(-X,t) = T_s \tag{9}$$

If the surfaces are subjected to convection, with convective heat transfer coefficient h, and free stream temperature T_∞ (eg. in blast freezer or other convective freezers), then the boundary conditions $(x = X\ )$ and $(x = -X)$ can be then defined as :

$$-k(T(x,t))\frac{\partial T(x,t)}{\partial x} = h(T(x,t) - T_\infty) \tag{10}$$

For flux boundaries such as a radiation thawing device the boundary conditions $(x = X\ )$ and $(x = -X)$ can also defined as:

$$-k\big(T(x,t)\big)\frac{\partial T(x,t)}{\partial x} = q \tag{11}$$

If the boundary conditions on either side are equal there is symmetry in the heat transfer, leading to a symmetry boundary at the center of the product $(x = 0)$

$$-k\big(T(0,t)\big)\frac{\partial T(O,t)}{\partial x} = 0 \tag{12}$$

In many practical cases however boundary conditions can be complicated and go beyond the above definitions. For instance in impingement freezing convective heat transfer h is not constant but a function of position and time [7]. The differential equations described previously can be solved for various geometries using various numerical techniques. The common numerical techniques used in engineering calculations are the finite element and the finite difference techniques. Irrespective of the numerical technique used for the solution, the general idea of the enthalpy method is the same. The idea is that, though specific heat C_p has a discontinuity at initial freezing point, enthalpy of the biological material does not have this discontinuity. The enthalpy only undergoes a sudden change in slope at the initial freezing point (figure 4) [8]. Also, enthalpy is a function of temperature. Hence if experimental data is available relating enthalpy to temperature, enthalpy at a specific temperature can be evaluated and vice versa (using figure 4 or associated data).

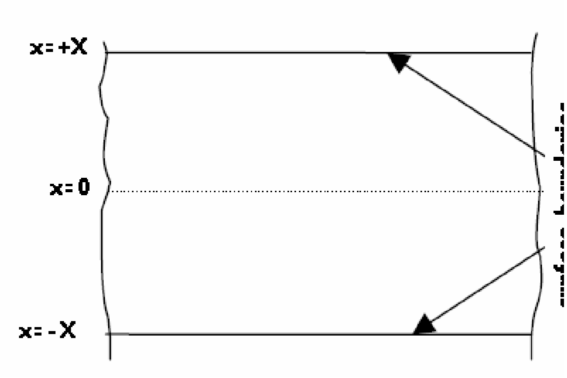

Figure 3. boundary conditions in a one dimensional slab

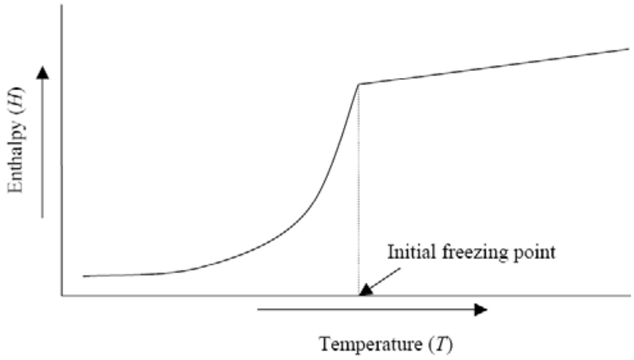

Figure 4. enthalpy variation with temperature for biological products

2.3. CALCULATION OF FREEZING AND THAWING PROFILES

Freezing-thawing simulation to calculate process times can be a useful tool in designing or modifying existing equipments or products. More recent research in areas of food freezing and thawing has indicated that product quality not only depend on the freezing time but also depends on the ice rate and specific heat value of the product and homogeneity of the freezing process (figure 5).

Another way to prevent drastic structural changes is to consider freezing and thawing rates. Studies have found that a change in freezing length can prevent dramatic structural changes. It has been shown that high freezing or thawing rates lead to the least structural disruption [9] [10]due to the size of the crystal formation and water movement that occurs during these processes (figure 6). In order to create a superior product, producers should be aware of these impacts and adjust their processing appropriately and consumers should know how to defrost their frozen strawberry product.

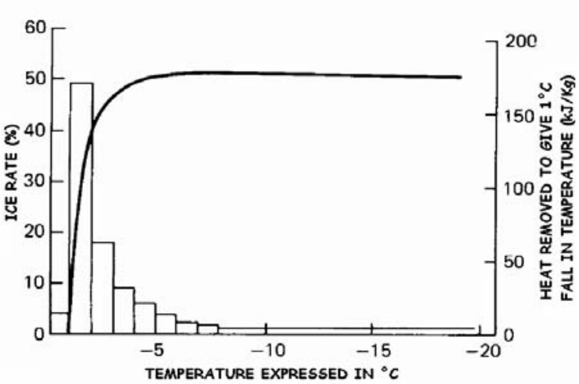

Figure 5. ice rate and specific heat in freezing process

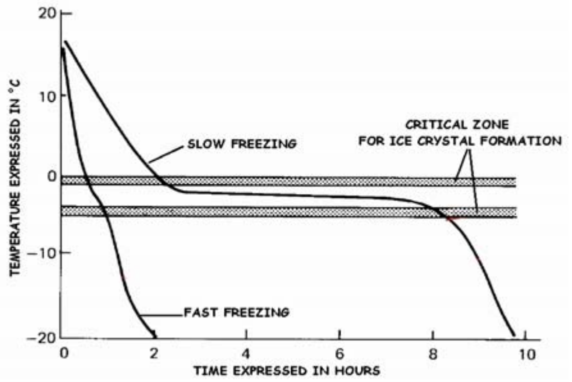

Figure 6. freezing specific zones

For example, if a food product is frozen in such a way that there is distinctly faster freezing on the surface that the center then it results in distinctly different quality attributes on the surface as compared to the center of the product. In cases of very rapid freezing such as cryogenic freezing or mixed cryogenic-mechanical freezing (figure 6), and such uneven freezing can even result in cracking and physical damage to the product. Hence for more advanced analysis of freezing processes it is useful to generate complete freezing profiles at various locations in the food product and temperatures.

3. MATERIEL & METHOD

Strawberries are most known for being eaten raw due to the fact that they are highly perishable. In general, strawberries have a maximum storage life of between 5 to 7 days at a temperature of 35.5°C and 95% relative humidity (Amrani, 2006). Processing strawberries is the result of its large production in morocco. Freezing is an alternative to improve the product availability, but it implies an increased cost and also losses in product quality. Strawberries were frozen by two methods: cryogenic freezing and combined (cryogenic-mechanical) freezing. Strawberries were washed and desinfected before been procesed. The mechanical step was carried out in a blast cold air freezer at –25°C and with a speed of 2.6 m/s. The cryogenic freezing was obtained using solid CO_2 .

4. RESULTS

The materials were stored for 10, 20 and 30 days, at –19 ± 2°C. The results indicated that: mixed cryogenic- mechanical freezing was carried out at –12°C in 19 min, while mechanical freezing was carried out at –18°C in 154 min. There were no significant differences in the texture and chemical properties between the freezing samples, although differences between fresh and frozen strawberries were observed. The frozen strawberries contained (g/100 g): moisture 89.09-89.54; reducing sugars 2.84- 2.85. Evidence indicates that the freezing mixed process with CO_2 and mechanical has no significant detrimental effect on nutritive value. It was concluded that this method is better than the mechanical, for this kind of products since there is a considerable time and energy saving. Comparative curves of mixed (cryogenic-mechanical) freezing and cryogenic freezing are shown in figure 7. A difference of 2.7 min between cryogenic freezing A1 (16.3 min) and combined freezing at-8°C (A3) and -12 °C (A4) (19 min) is observed.This result indicates that time of mechanical step is considerably reduced when cryogenic freezing is used first so that the strawberry temperature reaches –18°C in only 19 minutes. Wheras the mechanical freezing take 154 minutes to reach the same temperature, as shown in figure 8. That's why using the combined (cryogenic-mechanical) freezing allows important energy saving.

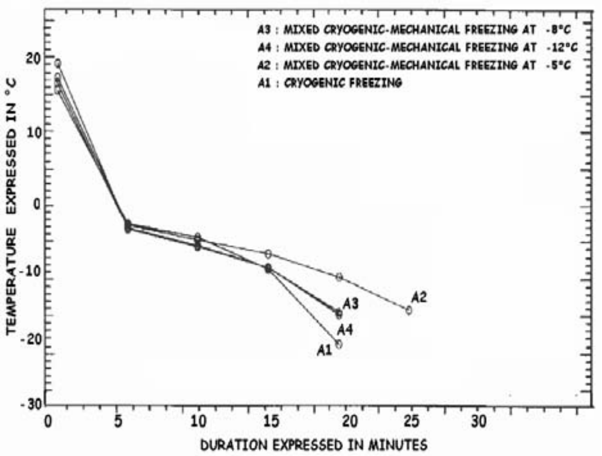

Figure 7: Cryogenic and combined cryogenic - mechanical freezing of strawberry

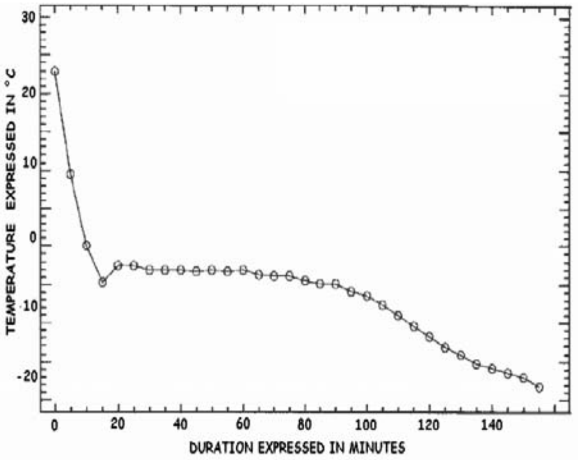

Figure 8 : Mechanical freezing of strawberry using ablast of cold air at –25 °C and 2.6 m/s speed

5. CONCLUSIONS

The time required for the combined (cryogenic- mechanical) freezing using temperatures of -8 and -12 °C during cryogenic step is 19 min, where as at –5°C,25 min were necessary. These durations represent a great saving of energy if it is considered that in the mechanical freezing, the time to reach the same temperature was of 154 min. This method of freezing is recommendable for fruits as the strawberry, since the quality of the product conserves so much in its appearance as in its nutritious value.

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