

Heat and Mass Transfer in Food Engineering

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ABSTRACT: Heat transfer in food processing is simultaneous heat and mass transfer in drying and frying, free convection heat transfer in thermal sterilization of cans, and phase change in freezing and thawing. Air drying, freeze drying, spray drying, and steam drying are accompanied by moisture transfer, which also undergoes phase change (evaporation). Heat transfer, together with moisture and vapor transfer, controls these processes. There is a need for deeper qualitative and quantitative understanding of the heat and mass transfer mechanisms underlying various techniques for food production, processing, preservation and storage. Several classes of food-processing problems are presented where advances can be made on the basis of improved understanding of heat and mass transfer mechanisms. This is important for the development of new food sources, for more economical and energy-efficient processing of food from existing sources, for better food quality and quality control, and for adherence to new regulations. Microwave (MW) drying is a rapid dehydration technique that can be applied to specific foods increasing concerns over product quality and production costs have motivated the researchers to investigate and the industry to adopt microwave drying technology.

KEYWORDS: Heat transfer, mass transfer, food processes, microwave drying.

I.INTRODUCTION

1.1 Heat Transfer Principles: Air during retort come-up and for draining (D), outlet ports for venting the retort at the end of the cycle (C), and a safety and pressure relief valve (F). A pocket for instruments, a thermometer, temperature-recording probe, and a pressure gauge is located on the side of the vessel. The operating cycle of this type of a retort involves bringing the retort up to a temperature of around 121°C. Steam is then allowed to pass through the vessel so that all air in the retort and between the cans is removed (venting) before the retort is finally brought up to the operating pressure and processing temperature. At the end of the processing time, the steam is turned off, and a mixture of cooling water and air is introduced into the retort to cool the cans. The purpose of the air is to maintain the pressure in the retort, following the condensation of the residual steam after the initial introduction of cooling water. The containers may deform because of the pressure difference between inside and outside of the container if this pressure is not maintained.

The recent focus on thermal sterilization of foods is to improve the rates of heating, in order to increase production rates and minimize damage to product quality. In most applications these two types of heat transfer occur simultaneously, but one type may be more important than the other. *Steady-state* heat transfer takes place when there is no change in temperature with time.

1.2. Unsteady-State Heat Conduction: In food processing, there are many situations where temperature is a function of time. The calculations of unsteady-state heat transfer are usually complicated and involve solving the Fourier equation, written in terms of the partial differential equation in three dimensions. In unsteady-state heat transfer, the temperature within a food during processing depends on the time and position. The temperature changes are influenced by

1. the initial temperatures of the heated body
2. the temperature of the heating medium
3. the surface heat transfer coefficient (heat transfer coefficient at all interfaces as well as where convection is involved)
4. the thermal conductivity, specific heat, and density of the food and their variation with temperature and composition

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The basic equation for unsteady-state heat conduction in one-space dimension (x) is

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p} \frac{\partial^2 T}{\partial x^2} \text{-----(1)}$$

where $\partial T/\partial t$ is the change of temperature with time, ρ is the density (kg m^{-3}), C_p is the specific heat capacity ($\text{J kg}^{-1}\text{K}^{-1}$), and k is the thermal conductivity ($\text{W m}^{-1}\text{K}^{-1}$).

When a solid piece of food is heated or cooled by a fluid, the resistance to heat transfer is mainly controlled by the surface heat transfer coefficient (h) and the thermal conductivity of the food (k)^[1]

$$Bi = \frac{h\delta}{k} \text{ These two factors are related by the Biot number (Bi):}$$

------(2)

where δ is the characteristic dimension or heat transfer path length in the solid (m). At small Bi values (>0.2), the surface film is the main resistance to heat flow; in this case, the assumption of negligible internal (conductive) heat transfer resistance in the solid food is valid. However, in most applications the thermal conductivity of the food limits the rate of heat transfer ($Bi > 1$).^[2]

1.3. Free Convection

When a fluid's temperature changes, the resulting changes in density establish natural convection currents, which occur as a result of bulk movement of the fluid, such as the movement of liquid inside a can during sterilization. Obviously, heat transfer by conduction occurs simultaneously but is generally negligible compared to convection heat transfer (Karl et al., 1975). The rate of convection heat transfer is governed by Newton's law of cooling. This law states that the rate of heat transfer by convection is directly proportional to the heat transfer area and the temperature difference between the fluid and heating/cooling surface:

$$Q = h_s a (T_{bu} - T_s) \text{-----(3)}$$

where Q is the rate of heat transfer (W), a is the surface area (m^2), T_s is the surface temperature, T_{bu} is the bulk fluid temperature, and h_s is the surface or film heat transfer coefficient ($\text{W m}^{-2} \text{K}^{-1}$).

$$\text{Nusselt number } Nu = \frac{hd_v}{k}$$

$$\text{Prandtl number } Pr = \frac{C_p \mu}{k}$$

$$\text{Grashof number } Gr = \frac{d_v^3 \rho^2 g \beta \Delta T}{\mu^2} \text{-----(4)}$$

where h is the heat transfer coefficient at the solid liquid interface ($\text{W m}^{-2} \text{K}^{-1}$); d_v is the characteristic dimension (m), which may be the height or diameter of the can, as will be discussed later; k is the thermal conductivity of the fluid ($\text{W m}^{-1}\text{K}^{-1}$); ρ is the density (kg m^{-3}); C_p is the specific heat capacity ($\text{J kg}^{-1}\text{K}^{-1}$); μ is the viscosity (N s m^{-2}); g is the acceleration due to gravity (m s^{-2}); β is the thermal expansion coefficient (K^{-1}); and ΔT is the temperature difference ($^{\circ}\text{C}$).^[4]

II. RELATED WORK

2.1 Thermal properties of food: Knowledge of the thermal properties of food is required in order to evaluate the heat transfer in food products. Therefore, a composition-based prediction method was used to obtain the thermal properties of food. The thermal properties are described by major components found in food such as: proteins, fat, carbohydrate, fibers, ash and water/ice. The composition data is stated as mass fraction and given in [1] and [2] for different food products such as vegetables, fruits, meat, etc. The thermo physical properties of each component are subsequently

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described by temperature dependent mathematical models in the temperature range of -40oC to 150oC. The properties were evaluated in the global expression window in Comsol. Knowing the composition as well as the thermal properties of the different components makes it possible to find the apparent properties of the food product. A different approach is used for the evaluation of the properties in the unfrozen and frozen region of the food. In order to evaluate which approach is to be used, determination of the initial freezing point is required. Pham Q.T. [3] has suggested the following equation for evaluation of the initial freezing point based on the composition data of the product:^[5]

$$T_f = -0.141 - 4.36 \frac{X_o}{X_{wo}} - 43.5 \frac{X_a}{X_{wo}} \text{-----(5)}$$

Whether the temperature of the product is above or below the initial freezing point the thermal properties of the food are calculated according to one of the following approaches:

Unfrozen food (T > Tf) The density of the food product is calculated according to the following equation:

$$\rho = \frac{1-\varepsilon}{\sum \frac{X_i}{\rho_i}} \text{-----(6)}$$

The specific heat capacity in the unfrozen part of the food is obtained from the mass average of the heat capacities of the components in the food product

$$Cp_w = \sum Cp_i X_i \text{-----(7)}$$

The thermal conductivity is described by means of a Maxwell type model. The dispersed phase is air (if present) and the continuous phase in the equation is obtained from the mass average of the conductivities of the remaining components in the food product^[7]

$$\lambda = \lambda_c \frac{2\lambda_c + \lambda_d - 2\varepsilon(\lambda_c - \lambda_d)}{\lambda k_c + \lambda_d + \varepsilon(\lambda_c - \lambda_d)} \text{-----(8)}$$

$$X_{ice} = \frac{1.105 * X_{wo}}{0.7138 + \frac{\ln(T_f - T + 1)}{1}} \text{-----(9)}$$

Frozen food (T ≤ Tf) The ice fraction during freezing is determined by the following equation given by [1]:

Knowing the fraction of ice, the thermal properties of the food during freezing can be obtained. The density of the food product is calculated according to equation 2, however, now including the mass fraction of ice.

$$Cp_w = \sum Cp_i X_i - L_f \frac{\partial X_{ice}}{\partial T} \text{-----(10)}$$

The latent heat of fusion is accommodated in the description of the apparent specific heat of food during freezing.

Thermal conductivity is determined in two steps and is based on equation 4. First, ice is used as a dispersed phase (if

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present). Secondly, air is used as dispersed phase (if present) and continuous phase is the previously obtained conductivity.

2.2 Heat transfer and reactions in foods:Foods are physically complex fluids and soft solids, with rheological and material properties that are time- and process-dependent and which have a natural variation. It is thus difficult to specify the physics in such a way as to allow accurate prediction of the process. Some safety margins are added to ensure that every part of the material is safe.

2.3 Milk protein:Unlike tomato paste, milk deposit cannot be removed by water alone. The force required to disrupt and remove the milk protein deposit has been measured without chemical being used and with cleaning chemical containing 0.5 wt% NaOH, used.

2.4 Cohesive and adhesive structures

It is possible, by setting the micromanipulation probe to pass above the disc, to leave deposit on the surface. In this case the force measured by the probe will correspond to that required to break the cohesive forces between parts of the deposit. This has been done for both types of deposit. For tomato, the force required for partial removal of the deposit exceeds that for the total removal,

III. EXPERIMENTAL WORK

In all experiments, the microwave oven was brought to the operating temperature by heating 1000 ml of distilled water in a glass beaker for 5 min before the first run of the day. The potato samples were placed on Petri dishes in the center of the microwave oven cavity. Throughout the experimental run the sample weights were continuously recorded at predetermined time intervals until no discernible difference between subsequent readings was observed. The moisture content value was determined as^[12]

$$M = (W_t - W_d) / W_d$$

Where M is moisture content, W_t is the weight of sample (g) at any time and W_d is the weight of the dried sample.

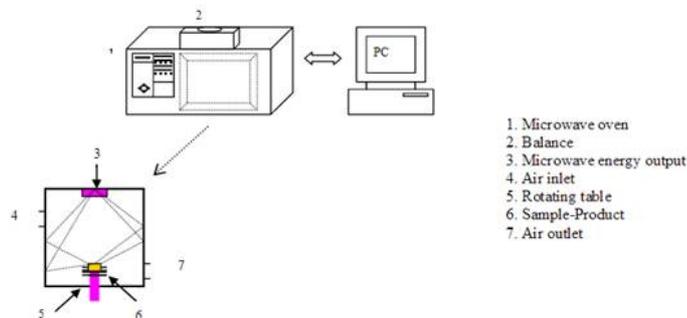


Figure No: 3 Microwave drying systems

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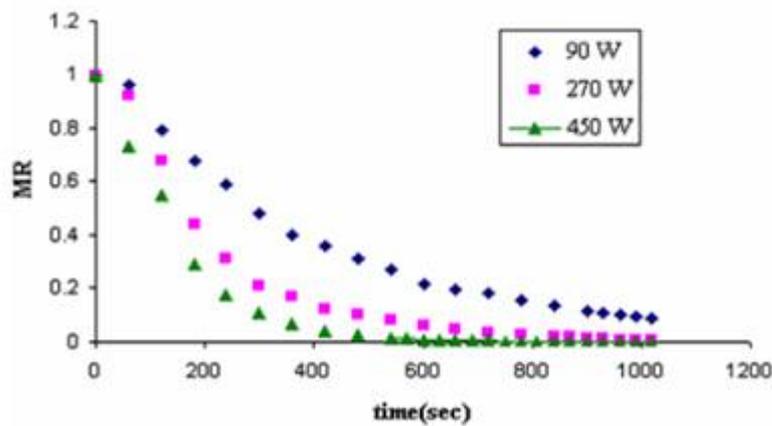
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IV.RESULT AND DISCUSSION

Throughout the experimental run the sample weights were continuously recorded at regular time intervals until no discernible difference between subsequent readings was observed.



Graph No: 4.1 Drying Curve

V. CONCLUSION

Based on the results of this study, the conclusions were drawn. Drying took place mainly in the falling rate period followed by a constant rate period after a short heating period. The drying rate increases with increasing the microwave power or sample diameter. An increase in slab diameter results an increase in the drying coefficient It is because of sudden and volumetric heating, generating high pressure inside the potato samples, resulted in boiling and bubbling of the samples.

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