

Heat and Mass Transfer in Apple and Potato Slices

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ABSTRACT: Considering that the growth of global population is closely correlated with environmental pollution, food production and preservation is becoming essential issue. Drying represents the simultaneous heat and mass transfer and is the oldest method for preventing bacteria growth which causes deterioration and spoilage of the food. Heat is transferred by conduction, convection, and radiation, while mass diffusion occurs when there is a gradient in the concentration of the species. For the purpose of this paper, series of experiments of far infrared vacuum drying of apple and potato slices have been done, for heaters temperatures of 120, 140, 160, 180 and 200°C and pressure in vacuum chamber of 20, 40, 60 and 80 kPa. The results show that decreasing of vacuum pressure in the chamber and increasing of heaters temperature, result on decreasing of drying time for both samples. **KEYWORDS:** Heat and mass transfer, experimental research, drying.

I. INTRODUCTION

Heat transfer from one point to another occurs only if there is a temperature difference, meaning, if there is a temperature gradient. In general, heat is transferred by conduction, convection, and radiation. If a temperature gradient exists in a stationary medium, which may be a solid or a fluid, then it's refer to conductively heat transfer. In the case when heat transfer occurs between a surface and a moving fluid when they are at different temperatures, it refers to convection. Thermal radiation is a heat transfer between surfaces with different temperatures, which emit energy in the form of electromagnetic waves⁴.

Conductive heat transfer can be explained through Fourier's law for a one-dimensional plane wall with rate equation⁹:

$$j_q = -\lambda \nabla T$$

The heat flux j_q (W/m²) is the heat transfer rate in the x-direction per unit area perpendicular to the direction of transfer and it is proportional to the temperature gradient, ∇T , in this direction. The

parameter λ is known as the thermal conductivity (W/m·K).

Bulk, or macroscopic, motion of the fluid in the presence of a temperature gradient, contributes to heat transfer. This is known as convection heat transfer¹⁰. This could be expressed by the Newton's law of cooling:

$$j_q = h(T_s - T_f)$$

Where, j_q (W/m²) is convective heat flux proportional to the difference between the surface and fluid temperatures respectively and parameter h (W/m²·K), termed as convection heat transfer coefficient.

Thermal radiation is energy emitted by matter that is at a nonzero temperature by electromagnetic waves (or alternatively, photons) and if the transfer of energy by conduction or convection requires the presence of a material medium, radiation does not¹¹. Actually, radiation transfer occurs most efficiently in a vacuum. The emissive power, E (W/m²) is prescribed by the Stefan–Boltzmann law:

$$E = \sigma T_s^4$$

Where T_s is the absolute temperature (K) of the surface and σ is the Stefan–Boltzmann constant (5.67x10⁻⁸ W/m²·K⁴).

Since the similar physical mechanisms are associated with heat and mass transfer by diffusion, the corresponding rate equations are of the same form¹². The rate equation for mass diffusion is known as Fick's law and it defines a second important transport property, namely, mass diffusivity.

In the time when global population is growing and environmental pollution is increasing, food production and preservation is becoming essential issue. Mechanical, physical, chemical and microbial effects could be cause for food deterioration and spoilage, as well¹.

Since the water activity in the food is closely correlated with the bacteria growth, it is very important to remove the water from the food, as a media which is suitable for bacteria growth, in order to prevent food of deterioration and spoilage².

Removing water from the food should ensure its quality, edibility and the nutritive value for future use, so the oldest method for food preservation is drying. Thermodynamically speaking, drying is simultaneous heat and mass transfer process and its drying kinetic depends of thermophysical properties of the material, such as thermal diffusion and mass diffusivity. In last decades, many papers are correlated with determination of thermophysical properties in order to predict and calculate drying kinetics and thermal diffusion and mass diffusivity for different vegetables and fruits^{6, 7}.

The apples and potatoes are very important foods in many countries in the world. Billions of people daily consumed apples and potatoes and their survival depend on it⁸. There are dozens of types of apples and potatoes and they are grown in most of the countries.

II. EXPERIMENTAL RESEARCH

On figure 1 is presented experimental setup for far infrared vacuum drying research of 3 mm thick apple and potato slices and is designed to simulate real dryer. In order to record changes in moisture content and temperature of the apple and potato samples, series of experiments are realized for heaters temperatures of 120, 140, 160, 180 and 200°C and pressure in vacuum chamber of 20, 40, 60 and 80 kPa³.

Fig.2 and 3 show the change in the average moisture content of apple pieces for different values of the absolute vacuum in the vacuum chamber, 20, 40, 60 and 80 kPa at a constant temperature of the heaters, $t_g = 120^\circ\text{C}$ and for different values of the temperature of the heaters 120, 140, 160, 180 and 200°C, with a constant value of the absolute pressure in the vacuum chamber, $p = 80 \text{ kPa}$.

Fig.4 and 5 show the change in the average moisture content of potato pieces for different values of the absolute vacuum in the vacuum chamber, 20, 40, 60 and 80 kPa at a constant temperature of the heaters, $t_g = 120^\circ\text{C}$ and for different values of the temperature of the heaters 120, 140, 160, 180 and 200°C, with a constant value of the absolute pressure in the vacuum chamber, $p = 80 \text{ kPa}$.



Fig. 1. Experimental setup

1 - vacuum pump, 2 - separator, 3 - vacuum chamber, 4 - vacuum-meter, 5 – temperature controller, 6 - vacuum regulator, 7 - micro thermocouples, 8 -computer interface, 9 - A/D converter, 10 - personal computer,

In tables 1 and 2 are presented the experimental results for heaters temperatures of 120, 140, 160, 180 and 200°C and pressure in vacuum chamber of 20, 40, 60 and 80 kPa, where t_g is heaters temperature, p is pressure in vacuum chamber, τ is time, t_0 is initial temperature of the samples, u_0 is initial average moisture of the samples and u_f is final average moisture of the samples.

Figures 2, 3, 4 and 5 show that decreasing of vacuum pressure in the chamber and increasing of heaters temperature, result on decreasing of drying time for both samples.

Table 1. Experimental conditions for apple slices

Experiment	t_g [°C]	p [kPa]	τ [min]	t_0 [°C]	u_0 [kgkg ⁻¹]	u_f [kgkg ⁻¹]
E2.1	120	20	110	24.51	5.73	0.18
E2.2	120	40	120	24.61	5.73	0.11
E2.3	120	60	130	24.60	5.74	0.06
E2.4	120	80	150	24.67	5.74	0.01
E2.5	140	20	90	24.68	5.72	0.22
E2.6	140	40	100	24.60	5.74	0.10
E2.7	140	60	110	23.77	5.76	0.04
E2.8	140	80	120	23.97	5.78	0.02
E2.9	160	20	70	23.98	5.65	0.07
E2.10	160	40	80	24.58	5.67	0.03
E2.11	160	60	80	24.55	5.69	0.04
E2.12	160	80	90	24.73	5.70	0.01
E2.13	180	20	60	24.98	5.69	0.06
E2.14	180	40	60	23.65	5.74	0.10
E2.15	180	60	60	25.26	5.78	0.16
E2.16	180	80	70	24.95	5.82	0.06
E2.17	200	20	50	25.27	5.64	0.10
E2.18	200	40	50	25.13	5.67	0.15
E2.19	200	60	60	24.95	5.70	0.03
E2.20	200	80	60	23.69	5.73	0.03

Table 2. Experimental conditions for potato slices

Experiment	t_g [°C]	p [kPa]	τ [min]	t_0 [°C]	u_0 [kgkg ⁻¹]	u_f [kgkg ⁻¹]
E1.1	120	20	210	23.85	5.36	0.02
E1.2	120	40	230	23.95	5.28	0.01
E1.3	120	60	240	23.93	5.18	0.01
E1.4	120	80	260	23.37	5.10	0.01
E1.5	140	20	150	23.51	5.19	0.03
E1.6	140	40	170	23.78	5.30	0.02
E1.7	140	60	190	23.93	5.30	0.01
E1.8	140	80	200	23.53	5.34	0.01
E1.9	160	20	100	24.07	5.28	0.13
E1.10	160	40	110	25.07	5.20	0.07
E1.11	160	60	130	24.80	5.23	0.02
E1.12	160	80	150	23.78	5.30	0.02
E1.13	180	20	70	24.03	5.25	0.19
E1.14	180	40	80	24.42	5.28	0.10
E1.15	180	60	90	24.79	5.26	0.07
E1.16	180	80	110	23.59	5.31	0.02
E1.17	200	20	60	24.82	5.24	0.23
E1.18	200	40	70	24.85	5.24	0.08
E1.19	200	60	80	24.95	5.23	0.04
E1.20	200	80	100	23.74	5.25	0.01

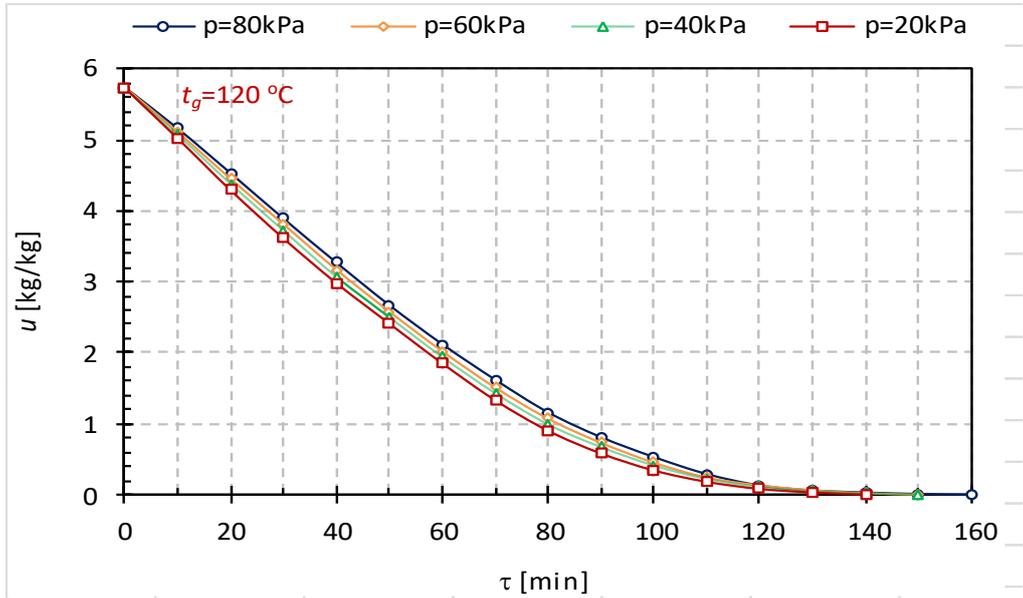


Fig. 2. Change in average moisture with time, apple $t_g = 120^\circ\text{C}$ and $p = 20, 40, 60, 80\text{ kPa}$

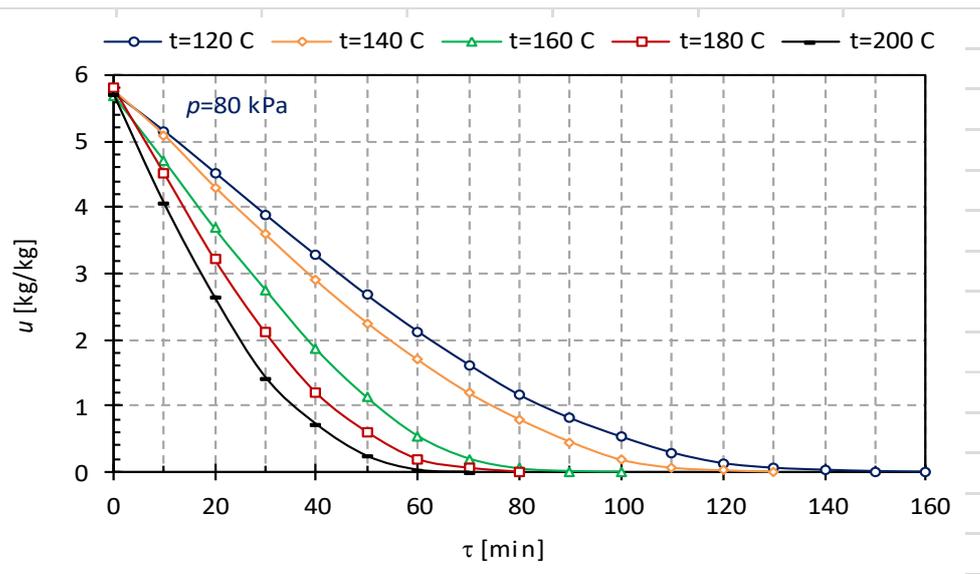


Fig. 3. Change in average moisture with time, apple $p = 80\text{ kPa}$ and $t_g = 120, 140, 160, 180, 200^\circ\text{C}$

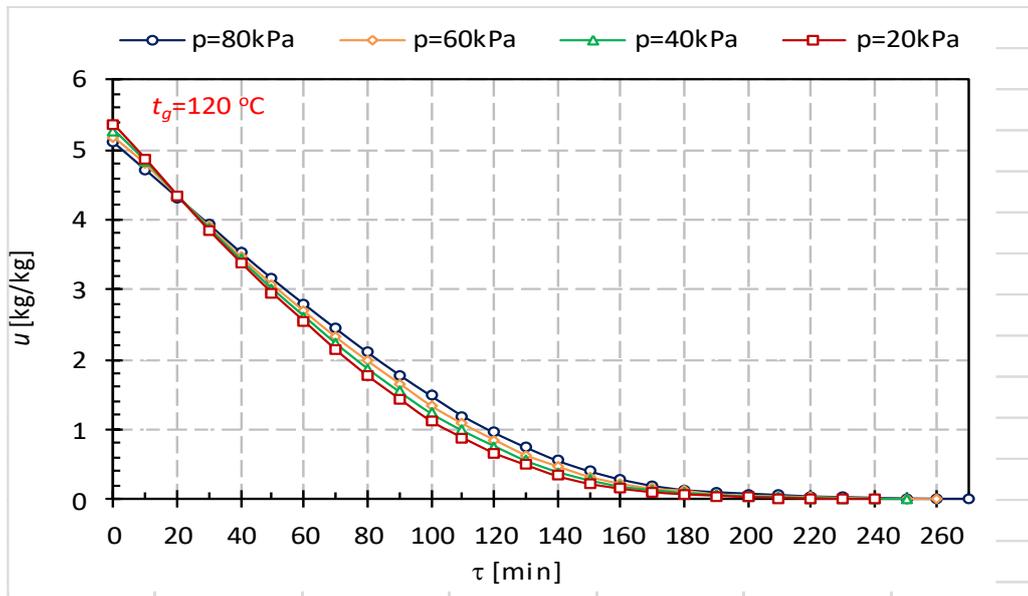


Fig. 4. Change in average moisture with time, potato $t_g = 120^\circ\text{C}$ and $p = 20, 40, 60, 80$ kPa

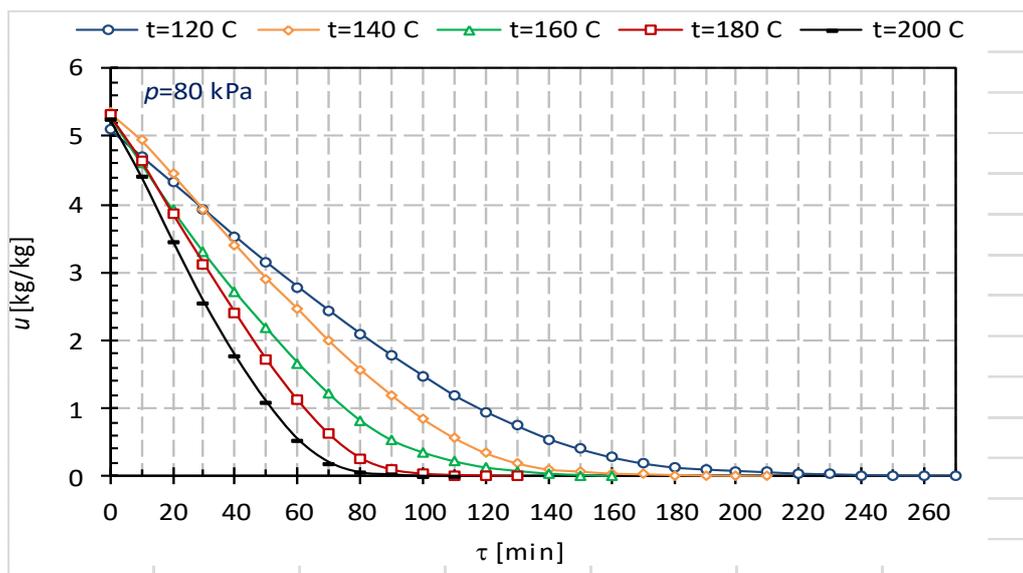


Fig. 5. Change in average moisture with time, potato $p = 80$ kPa and $t_g = 120, 140, 160, 180, 200^\circ\text{C}$

III. CONCLUSION

Since the growth of global population is closely correlated with environmental pollution, food production and preservation is becoming essential issue. There are many methods for food preservation, but drying is the oldest one to prevent bacteria growth which causes deterioration and spoilage of the food.

Thermodynamically speaking, drying is simultaneous heat and mass transfer process and its drying kinetic depends of thermophysical properties of the material, such as thermal and mass diffusivity. In general, heat is transferred by

conduction, convection, and radiation and mass diffusion is explained by Fick's law.

Series of experiments of far infrared vacuum drying of apple and potato slices are realized for heaters temperatures of 120, 140, 160, 180 and 200°C and pressure in vacuum chamber of 20, 40, 60 and 80 kPa³. It is concluded that decreasing of vacuum pressure in the chamber and increasing of heaters temperature, result on decreasing of drying time for both samples. Similar conclusions have been obtained when drying various fruits such as: pear⁶ and quince¹³.

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