GRADUATE AND POSTDOCTORAL STUDIES

McGILL UNIVERSITY

[redacted]

FINAL ORAL EXAMINATION

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

OF

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DEPARTMENT OF FOOD SCIENCE AND A

ABSTRACT

Pressure-driven fluid flow is an inevitable consequence of high pressure processing of porous biological materials confined in a fluid phase. In this study, the fluid migration into porous biomaterials such as fruits and vegetable tissues was fully characterized. In a major part of this study, various computational procedures were introduced to model such transport phenomena.
First, the fluid migration trend was thoroughly evaluated into the fresh-cut apple as the selected porous medium. The mass transfer was monitored at 100 to 600 MPa pressure level and 0 to 30 min pressurization time. The mass transfer during pressure holding time fitted the Fick's second law. Using inverse methods of parameter estimation algorithms, the calculated diffusivity values ranged 4.38×10^{-9} to 2.19×10^{-8} $m^2 s^{-1}$. Moreover, the effect of pressurization come-up time at different pressurization rates was found to be a key factor affecting the final mass transfer. In this regard, an inverse linear relationship was seen between the come-up time and the final mass intake. Considering both pressure come-up and holding time, a comprehensive model was proposed to evaluate the mass intake as a function of pressurization rate, come-up time, final pressure level, and pressure holding time. Also, simplified linear models were introduced for specific industrial applications regarding the final mass intake at constant pressure levels and different holding times. In addition, A novel algorithm was developed to couple the identified Fickian mass transfer to Darcy's equation for unsaturated porous media. The coupling led to an approximation of transient flow-induced pressure gradient profile within the tissue. The numerical simulation was also conducted assuming various scenarios regarding the effective permeability of the tissue. A variable permeability function was also introduced using the Kozney-Carman model to consider the pressure-induced inhomogeneity within the texture of the porous biomaterials. Along with the numerical solutions, analytical solutions to Darcy's law were used to approximate the permeability range as a function of the approximated flow front function.

The studied phenomenon was introduced as "high pressure impregnation (HPI)" in case of intentional addition of selected solutions into the porous media. In this regard, novel concepts were introduced to demonstrate the potential capabilities

frozen samples showed a textural improvement during impregnation of fresh-cut apple with chitosan at mid-level concentrations.

Microstructural analysis and subsequent image analysis techniques were used to demonstrate the flow migration within the tissue. Impregnation of dyes was introduced and conducted as a strong method of evaluation of microscopic flow paths. The obtained images were also used to identify endurance of porous structure of the medium during pressurization. In addition, impregnating food colors helped a visual understanding and verification of numerical of simulation of Fick’s law for fluid transfer within the tissue. The watershed algorithm was used to identify the flow paths inside the porous media. It was seen that flow path were perpendicular to the surface at the outer layer of the geometry. Scanning Electron microscopy (SEM) was also conducted to evaluate the textural changes after HPI. The results showed that the incompressibility of impregnant helped the tissue to maintain its cellular arrangement. However, certain changes in the path directions and cell wall shrinkages were done. The observations were also used to obtain the variable porosity model parameters.

Finally, HPI was also introduced as a novel method of impregnation of W/O emulsions in various fruits. At first, the effect of pressure on emulsion stability parameters such as particle size, viscosity, and pH was studied. A pseudo-first order kinetics model was used to evaluate the time transient impregnation yield at 100 MPa. Moreover, the effect of various levels of oil/emulsifier combinations showed an inverse relationship between the oil percentage and final mass intake. Light microscopy and Fourier transform infrared spectroscopy was used to validate the migration of droplets into the tissue.

CURRICULUM VITAE

UNIVERSITY EDUCATION

Ph. D. candidate in Food Science and Agricultural Chemistry, **2015- Present**, McGill University, Montreal, Canada.
Thesis Title: Fluid Migration into Biomaterial Porous Matrix under High Hydrostatic Pressure.

M. Sc. Food Engineering, **2011- 2013**, Isfahan University of Technology (IUT), Isfahan, Iran.
Thesis Title: Heat transfer of Cereal-based Baby foods in Semi-Rigid Aluminum container using Computational fluid dynamics.

B. Sc. Food Science and Technology, **2007-2011**, Isfahan University of Technology (IUT), Isfahan, Iran.

AWARDS

Graduate Mobility Award, **2018.**
Graduate Research Enhancement and Travel Award, **2016-2018.**
Graduate Excellence Fellowship Award, **2015-2018.**

Conferences

Oral Presentations

- **Vatankhah,** H., Ramaswamy, H., 2018., Modeling of High Pressure Impregnation of Apple cubes. Canadian Institute of Food Science & Technology National Conference (CIFST),Ontario, Canada.
- **Vatankhah,** H., and Ramaswamy, H. 2017., Modeling and characterization of pressure driven-fluid transfer into porous media during the high pressure holding time. Northeast Agricultural and Biological Engineering Conference (NABEC). Groton, CT, USA.
- Cadieux, B., **Vatankhah,** H., Ramaswamy, H., Goodridge, L., 2016., Studying the kinetics of destruction of Cl. Botulinum at different pressure and temperature levels. Institute of Food Technologists, Chicago, USA.
- Zamindar, N., **Vatankhah**, H., Shahedi, M., 2014. Heat transfer simulation and retort program adjustment for thermal processing of wheat based Haleem in semi-

characteristics and staling of gluten free bread. 21nd National Congress of Food Science and Technology. Shiraz, Iran.