Computer Simulation of Microwave Heating of Initially Frozen Sandwiches Using COMSOL Multiphysics Application Builder

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ABSTRACT

A computer simulator was created on the COMSOL Multiphysics platform. The simulator can be used as a powerful computational tool to enhance the understanding of the microwave heating process of initially frozen sandwiches and improve the design of microwavable sandwiches. The microwave heating system consists of the four components: waveguide, oven cavity, turntable and sandwich (five layers: bottom bread, burger, egg, cheese and top bread). A set of functions were created to determine the temperature and composition-dependent properties of individual components of sandwiches using the regression equations. Research was conducted to optimize the mesh size and time step in order to save computational time. The temperature and moisture of a food item at each node and time segment were calculated using the mathematical model and corresponding software solvers. A report can be generated at the end of the simulation and emailed to users.

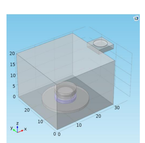
INTRODUCTION

The microwave heating rates and potential non-uniform temperature profile are functions of oven factors and load characteristics (such as composition, phase, size and shape). Microwave heating of foods is more food-dependent than conventional heating. Therefore, microwave heating profiles of each food ingredients should be clearly understood. It is also important to achieve temperature uniformity because large temperature variations in the product will damage the product quality due to excessive heating, drying and nutrient losses in overheated regions. Due to the large variation in food ingredient, uniform microwave heating at a desired temperate is rarely reached.

The objective of this project is to develop a COMSOL Multiphysics based microwave heating simulator to enhance the understanding of the microwave heating process of initially frozen sandwiches and improve the design of microwavable sandwiches.

PRODUCT AND PROCESS TO BE SIMULATED

Sandwich
(five layers: bottom bread, burger, egg, cheese and top bread)



Microwave oven
(waveguide, oven cavity and turntable)

Structure of the product:
- ❖ Arrangement of components
- ❖ Porosity of components
- ❖ Geometric dimensions of components

Chemical compositions:
- ❖ Water
- ❖ Protein
- ❖ Fat
- ❖ Carbohydrates
- ❖ Salt

Phase of water:
- ❖ Ice
- ❖ Liquid water
- ❖ Vapor

Multiple physics:
- ❖ Microwave transfer
- ❖ Heat transfer
- ❖ Mass transfer
- ❖ Phase changes
  - •Ice melting
  - •Water vaporization
- ❖ Coupling of multiple physics

Microwave generation:
- ❖ Frequency (e.g., 2.45GHz)
- ❖ Power output (e.g., 1000 W)

Waveguide:
- ❖ Location
- ❖ Dimensions

Cavity:
- ❖ Dimensions

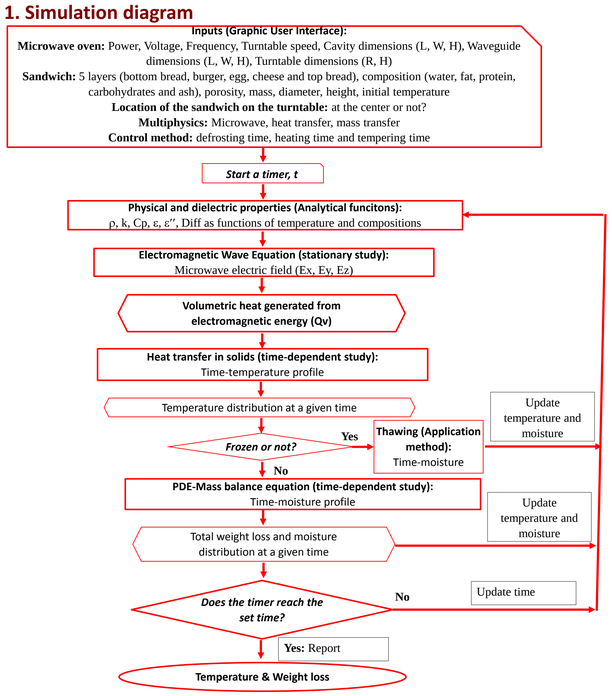
Turntable:
- ❖ Dimensions
- ❖ Rotational speed

Location of food product:
- ❖ At the center of the turntable or not

Operations:
- ❖ Defrosting
- ❖ Heating
- ❖ Tempering

METHODOLOGY

1. Simulation diagram



2. Mathematical model

- ❖ Microwave generation and transfer

$$\nabla\times\left(\frac{1}{\mu'}\nabla\times\vec{E}\right)-\frac{\omega^2}{c}(\varepsilon'-i\varepsilon'')\vec{E}=0$$

- ❖ Heat transfer

$$\rho c_{p,e}\frac{\partial T}{\partial t}=k\nabla^2T+Q_v$$

- ❖ Mass transfer

$$\frac{\partial X_w}{\partial t}=D\nabla^2X_w+\dot{X}_v$$

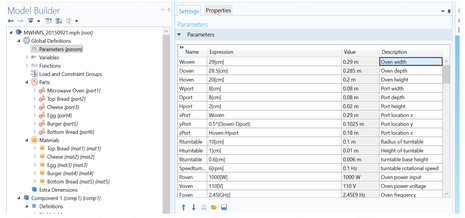
- ❖ Phase changes
  - •Ice melting
  - •Water vaporization
- ❖ Coupling of multiple physics

3. Prediction of the properties from temperature, composition and porosity

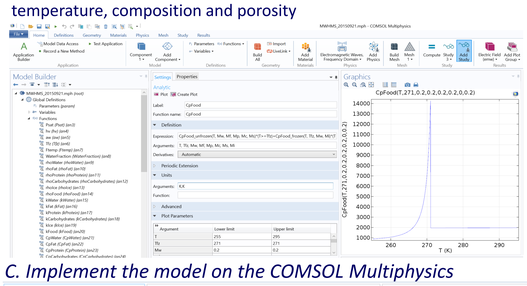
- ❖ Initial freezing point
- ❖ Ice content
- ❖ Specific heat
- ❖ Thermal conductivity
- ❖ Density
- ❖ Dielectric constant
- ❖ Dielectric loss factor
- ❖ Diffusivity

4. Implementation of the model in COMSOL Multiphysics

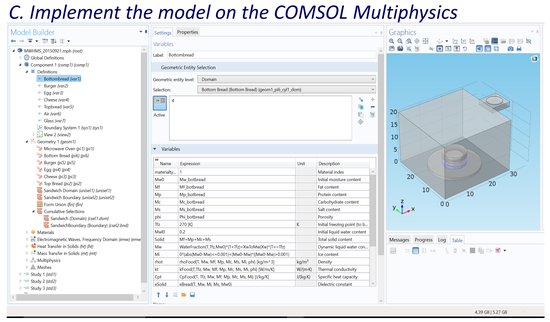
A. Global definitions of design and operating parameters, parts and materials



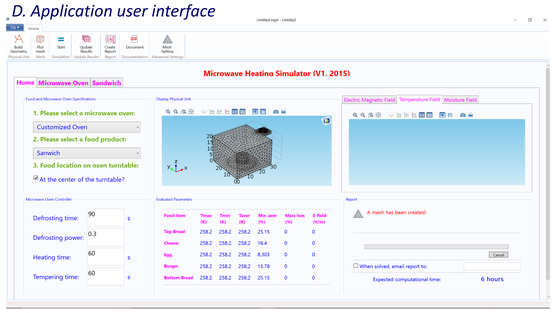
*B. Definitions of analytical functions to p*rediction of the properties from temperature, composition and porosity



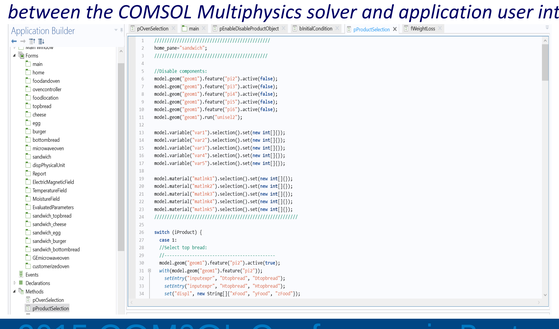
C. Implement the model on the COMSOL Multiphysics



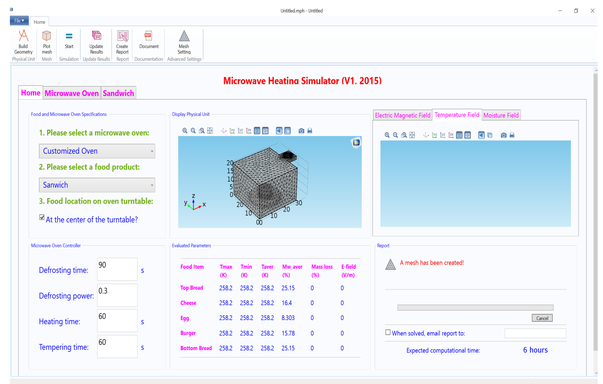
D. Application user interface

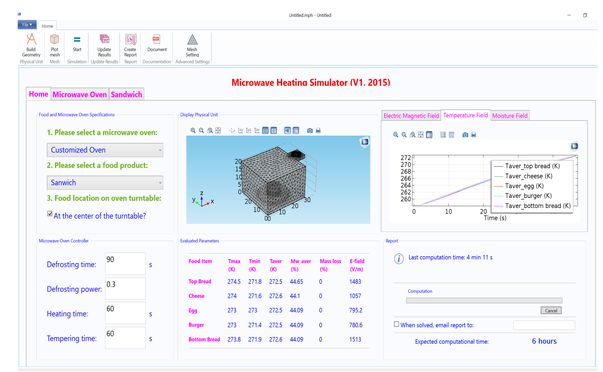


E. Creation of forms and application methods to establish the connection between the COMSOL Multiphysics solver and application user interface



RESULTS AND ANALYSIS





CONCLUSIONS

A computer simulator was created on the COMSOL multiphysics to be used as a powerful computational tool to enhance the understanding of the microwave heating process of initially frozen sandwiches and improve the design of microwavable sandwiches. A mathematical model was developed to describe system geometries, physical and dielectric properties, electromagnetic transfer, heat transfer and mass transfer. Three studies were conducted to solve the electromagnetic, heat transfer and mass transfer sub-models, respectively. A graphic user interface (GUI) was created using the Application Builder of the COMSOL Multiphysics 5.1for users to provide the specifications of the microwave oven, sandwiches and process control and visualize the simulation results. The simulator can be used to improve product design, improve process design and operation, enhance quality and safety control and evaluation of economics and environmental sustainability.

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