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Two Dimensional Analysis of Transport Phenomena Occurring During Convective Drying of Ginger

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Abstract: Drying is a preservation technique to reduce the water content of the food product to a safe level and to minimize biochemical reactions of the degradation and also to increase the shelf life of the product. Transport phenomena involved in drying process of food is considered in this study. The important parameters in drying process such as temperature, time, velocity and humidity were considered in the theoretical study of drying process of ginger. The parameters were studied by considering the simultaneous transfer of momentum, heat and mass transfer occurring in dryer when hot air flows over a wet cold food sample. The model used is the general model normally considered in predicting the real behaviour of drying process in dryer over a wide range of process and fluid-dynamic condition. The specific geometry of both dryer and moist object was considered. The physical and transport properties of both food and air are formulated as a function of local values of transport and moisture content. The non-liner unsteady-state partial differential equations were solved by means of COMSOL Multiphysics. The simulation results show the distribution of liquid water, vapour field and temperature in the moist object. It also show temperature and velocity distribution inside dryer. A careful study of the results will help to design a good dryer that will reduce energy wastage and give good product. The results also show that front side of the moist object dried faster than the rear side.

KEY WORDS: Drying, dryer, Food, Heat and mass transfer, COMSOL Multiphysics

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1.0 INTRODUCTION

Drying is the application of heat to remove moisture from agricultural product to a safe level that micro-organism will not be able to spoil it. It is one of the important ways of preserving agricultural products for later use. The heat must be carefully applied in such a way that it will not affect the natural properties of the product.

A lot of complications happen during drying process. If heat is not properly applied, it will affect the nutritional value, physical appearance and chemical composition of the final product. Moisture must be removed at appropriate rate (timing) and to a safe level because over dry and under dried product will not be properly acceptable in the market. Therefore, a careful study of distribution of heat during drying and movement of moisture will help in enhancing the product quality. The proper understanding of interaction between application of heat and moisture removal is needed for proper equipment design and reliable or good products.

The experimental investigation of the drying process is complex and expensive; therefore, modeling will be the appropriate tool that can be used to study the interaction between temperature, moisture, time and velocity during drying. The proper control and study of these parameters for a particular agricultural product will help in designing appropriate equipment and it will enhance the quality of the product with proper energy management (minimal wastage).

Many researchers have considered several physical, mathematical and numerical methods to describe the drying process. From the previous work, modeling is a very good tool to illustrate the relationship between different drying parameters and the results of the modeling help to get insight into drying mechanisms (Aversa, *et al*., [1], Ginear *et al*., [2] and Barati & Esfahani, [3]). Complex nature of transport phenomena that are involved in food drying makes it too difficult to provide an exhaustive analysis (Ruiz-Lopez *et al*., [4]). Some researchers considered mass transfer only in their study by assuming that the drying process is isothermal, this means that drying temperature is equal to air temperature (Hernandez, *et al*., [5], Simal, *et al*.,[6], Ben-Yoseph, *et al*., [7]). A more rigorous was developed by Ikediala, *et al*., [8] when simulation of the cooking process of Chicken patties was considered by studying heat and mass transfer processes. Ahmad, *et al*., [9] also considered both heat and mass transfer in studying transport phenomena involved in biscuit drying by microwaves. Therefore, simplified model have been proposed and still in use by the process designers. Esfahani *et al*., [10] investigated two dimensional analytical modeling of heat and mass transfer during drying. Their analysis makes it possible to predict that front face of the object dried faster than the rear face. That it was reduction in the convective heat and mass transfer coefficients that caused delay in the drying process of the backside of object. Curcio, [11], investigated the transport phenomena occurring during vegetable drying by studying the influence of important operation variables on system performance. His results shows that penetration of temperature and concentration are confined to two thin region that develop at the air-food interface and that as hot air passes over the object, the front part dry faster than the inner and the rear surface i.e increase in temperature but decrease in humidity. Crisrea *et al*., [12] investigated effect of controlled forced convection drying in food slabs. They found out that proper control of drying parameters especially temperature will lead to optimization and improved drying process that can give short drying time, minimum energy consumption and prevent material deterioration. All the above reviewed work considered half (symmetric) object. This paper considered the whole object and tried to investigate the effects of hot air around the object. The influence of the temperature and velocity on drying rate was considered i.e water and moisture movement during drying. The effect of side wall on the velocity of air was considered.

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2.0 METHODOLOGY

2.1 Model description

Drying process involves transfer of heat from air to the product surface by convection and transfer of heat to the inner layer of the product by conduction. This transfer of heat will cause water movement in vapour form from the inner layer and outer surface of the product to air and it will be convected out of the drying chamber by air movement. Air movement during drying process is very important and therefore, the effects of its movement must be properly studied. Also, water vapour diffusion within dehydrated material and its surface must be considered.

In this paper, moisture and heat transportation (for both air and agricultural products) and air velocity were modeled by transient momentum, mass and energy balance with references to drying process of rectangular shaped ginger.

The convective drying process of moist slab cut of ginger slice was study. Its length is 6 centimeter, L= 6 cm and height of 3 centimeter, H = 3 cm. Figure 1 illustrates the problem domain, with its boundary conditions, for the determination of external flow and temperature fields of the drying fluid around the object being drying. At the left side, inlet velocity and temperature are U_∞= 0.1 m/s and T_∞ = 293.15 K, respectively. Side walls are assumed at U_∞ and T_∞ too, and pressure outlet is considered as outlet condition of flow field.

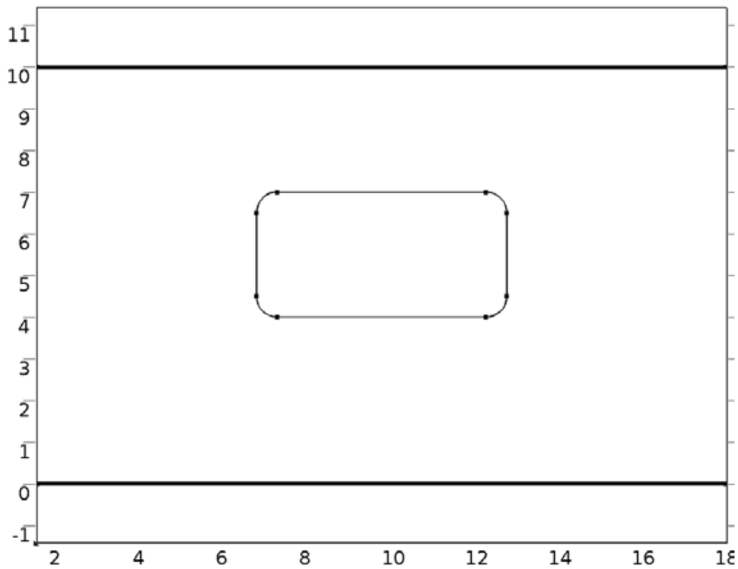

Figure 1: Drying slab geometry and its surrounding.

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Two assumptions are considered for this work: (i) moisture content independent thermo-physical properties of the moist object, (ii) negligible shrinkage or deformation of the moist object during drying. The governing two-dimensional heat and mass transfer equations under the above assumptions can be written as:

The mass conservation equation is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

The momentum equations are

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right)$$

The two dimensional unsteady state mathematical model was used to simulate the drying process.

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}$$

$$\frac{1}{D}\frac{\partial M}{\partial t} = \frac{\partial^2 M}{\partial x^2} + \frac{\partial^2 M}{\partial y^2}$$

The boundary and initial conditions of above equations are:
Initial conditions:

$$T(x,y,0) = T_i$$
$$M(x,y,0) = M_i$$

Left boundary conditions:

$$k\frac{\partial T(0,y,t)}{\partial x} = h(T - T_\infty)$$

$$D\frac{\partial M(0,y,t)}{\partial x} = h_m(M - M_\infty)$$

3.0 RESULTS AND DISCUSSION

All the simulation was performed assuming that the food sample is ginger with initial temperature equal to 293.13. The results of external flow analysis and heat and mass transfer inside the moist object are presented in this section. The inlet air comes in through the left hand of the rectangular section. The results as shown in figure 2 to 5 shows velocity, temperature, liquid water and vapour concentration.

The model can describe, at any time, all the profiles in both domains. Figure 2 shows air velocity field that develops in the drying chamber and around the drying object. It is observed there is a difference between what happens at the front side of the drying sample and rear side. The front side that is hit first by air velocity has low velocity when compared to the rear side. The velocity of air near the wall is very low compared to the one close to the surface of the moist object showing effect of wall on air movement (no slip boundary condition). There is a wake at the rear end of the object showing less contact of air with the moist object. This observation affects the drying rate of the object since air velocity affect heat and mass transfer at air-food interface.

Figure 3-5 show temperature, liquid concentration and vapour concentration in the air food interface. It is observed that front side has the highest temperature and water/vapour conservation. All these are as a result of air velocity together with temperature distribution.
The larger part of the drying chamber has constant value for either temperature or humidity. Also, because of high movement of air at the rear side of the moist sample, the temperature increased slowly.

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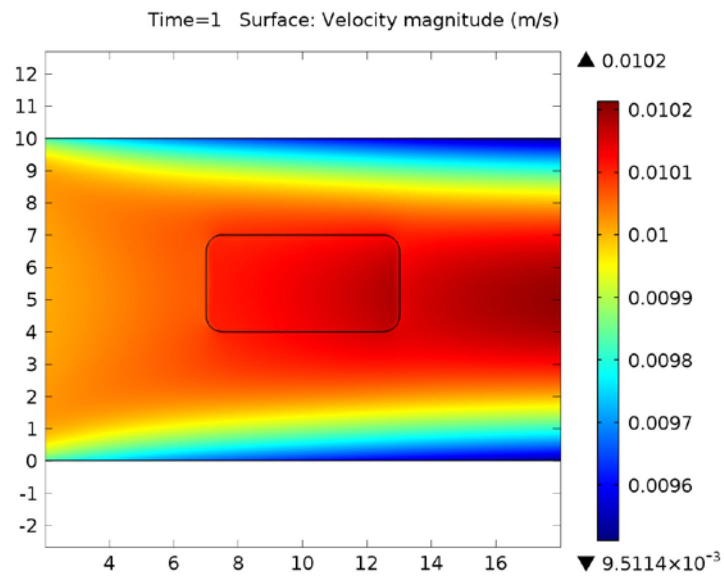

Figure 2: Velocity field distribution around the object and inside the dryer

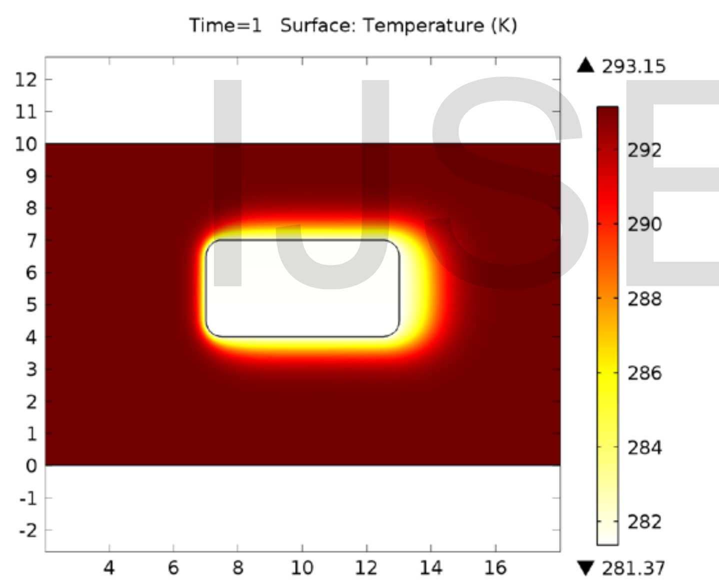

Figure 3: Temperature field distribution inside and around the drying object

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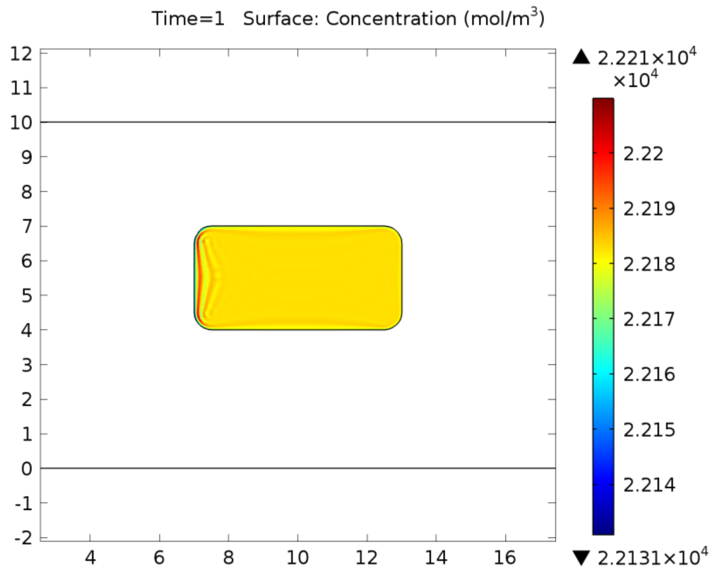

Figure 4: Liquid water concentration distribution inside the drying object

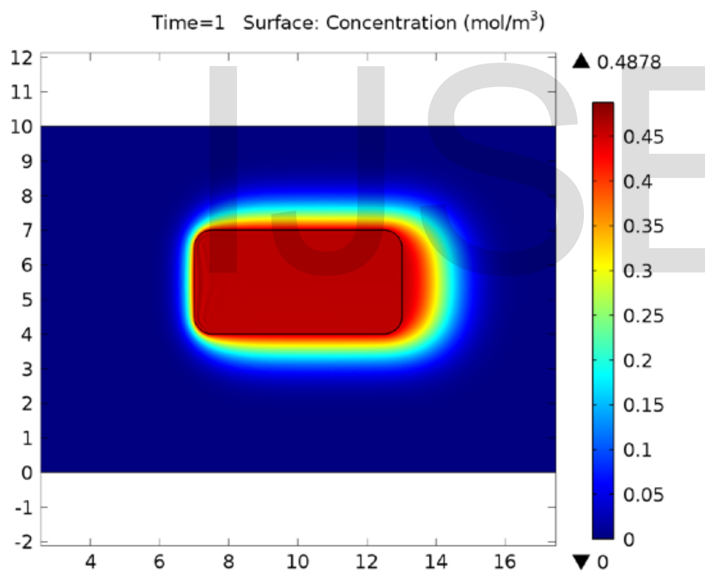

Figure 5: Vapour or humidity concentration distribution inside the drying object

4.0 CONCLUSIONS

The paper study effects of heat on moist object during drying by employing COMSOL multiphysics 4.3b. The effect of velocity on heat distribution was study and how it affects drying process. Also water and vapour distribution was shown and this type of study will help dryer designer in designing of dryer and also help on how and ways of applying heat on the moist object. It helps in the understanding of effect of side walls on the temperature and velocity of air. The side wall temperature will also affect the temperature inside the dryer and the effect of recirculation should be looked into to avoid moisture reabsorbtion by the drying object.

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