Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XLI
Broj 3, 2016.
Strane: 77 – 84

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XLI
No. 3, 2016.
pp: 77 – 84

UDK: 536.24

Originalni naučni rad
Original scientific paper

CFD SIMULATION OF COOLING OF CORIANDER SEED UNDER DIFFERENT MOISTURE CONTENT

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Abstract: CFD simulation of cooling during cryo-grinding of coriander seeds was performing to determine its residence time in conveyer. Coriander seed at different moisture content were simulated and the equations were solved over a defined space and time domain, discredited by computational grids and time steps. Simulation result shows that temperature of coriander seed reduces from 27 to -53ºC in 12 sec. The simulation also accounts the effect of moisture content on temperature distribution and time of cooling. The numerical simulation was further verified through cooling experiments with coriander seed by directly dipping them in liquid nitrogen. Simulation data well matched with experimental results. The chilling rate of seed was found to be time, product-temperature and moisture dependent.

Key words*: CFD simulation, heat transfer, moisture content, spices.*

INTRODUCTION

Computational fluid dynamics (CFD) is a simulation tool, which uses powerful computer and applied mathematics based fluid-flow modelling for the prediction of heat, mass and momentum transfer and optimize design for industrial unit processes [1, 2, 3, 4]. Some design engineers actually use CFD to analyse new systems before deciding which and how many validation tests need to be performed. It also facilitates deep analysis of local effects in a lot of equipment [5, 6] and results in an improved performance, reliability, scale-up, product consistency and higher plant productivity [7].

Recently, the application of CFD simulation has gained immense importance in food processing industry. CFD solutions are being used to develop equipment, optimise and processing strategies in the food industry and their rate of use has grown exponentially, as evidenced by the steady increase in peer-reviewed journal papers over the years. The many areas within the food industry where CFD has been routinely used to quantify governing physical phenomena include sterilisation [8], mixing [9], drying processes [10], belt dryer [11], vacuum cooling [12], cold store [13], heat and moisture transfer in stored grains [14], Natural Convection Cooling [15], convective heating [16], Natural Ventilation [17], Supercritical Fluid Extraction [18], evaporative cooling [19, 20], to name but a few, with the range of applications being continuously extended. The food and beverage industrial processes are used regularly to enhance quality, safety and shelf life of food stuffs [21] and links between CFD and the processes such as mixing, drying, cooking, sterilisation, chilling and cold storage are profound. Mathematical and numerical simulation have been perform by different researcher on different process like heat load [22], drying [4] and Natural Ventilation [17] etc., but none of the simulation study was focused on cryo-cooling of spice.

Spices are one of the most important constituents of Indian food. They are widely used in households, hotels, restaurants and food processing industries, either used in form of powder or whole to improve the flavour of food. A perfect grinding system of spices must reduce the size of product while maintaining good product quality in terms of favour and colour [23]. But, normal grinding process of size reduction generates heat. The temperature of the product rises in the range of 42°C to 95°C [24] resulting in loss of some volatile flavouring compounds and degradation of quality. It also depends upon the composition, moisture content and the method of grinding. Temperature rise during grinding process can be minimized to some extent by cold air or water circulation around the grinding machine or grinding in to two or more stage, although these techniques proves inefficient in reducing the temperature rise significantly. [23] developed a cryo-grinding system for spice where the spices were cooled before feeding to the grinder by using liquid N_2 (-195.6°C) and the temperature 10 to 30ºC below the freezing point of oil is maintained throughout the conveying zone by conveying and same temperature product were feed in to the grinder.

We, thus state that the present study is first study focussing on utilisation of CFD simulation to predict the time of cooling as well as temperature profile during cryo-cooling of spices (Coriander seed). The heat transfer during cryo-cooling process for determination of cooling time and temperature profile of spices with respect to different moisture content has been simulated and will aid in designing and scaling-up the precise system for cryo cooling.

MATERIAL AND METHODS

Sample preparation. Coriander seed samples were collected from the local market in Kharagpur and were maintained at different moisture content 8, 10 and 12% (w.b.). The physical and thermal properties of the seed were evaluated for CFD simulation and were previously discussed [25, 26].

Modelling the problem

*Cryo-cooling of spices***.** Cryo-grinding involves grinding the spices at low temperature. During the process, temperature of spices was reduced to a certain level (i.e. below the solidification point of coriander oil) to reduce the volatile loss. The spices were then transferred to grinder through cooling tunnel or conveyer in presence of liquid nitrogen. The time of Cooling is a deciding factor for travelling time of grain in the conveyer. Most of the heat were removed by liquid nitrogen which converts to gas and maintain the temperature during conveying. Single grains were selected to simulate the cooling process and geometry as described previously in another paper [25].

*The physical model***.** Considering the physical properties at different moisture content [25], spherical geometry (Figure 1) was used for simulation of coriander seed cooling. Liquid nitrogen was injected over the grain during cryo-cooling and hence, in simulation, it was assumed that the grain has been surrounded by cloud of liquid nitrogen. Computer three-dimensional modelling was used to simulate the heat transfer phenomena, the temperature profile and time of cooling. Also, an experimental study was conducted to confirm the results obtained through simulation.

a. *b.*

Figure1: Geometry of coriander seed before (a) and after meshing (b)

*Initial and Boundary conditions***.** The selection of boundary conditions was based on following assumptions:

a. Sphericity of coriander seed was considered as one value.
b. During cooling process, seed is clouded by liquid nitrogen.
c. There is no phase change in liquid nitrogen.
d. No heat loss occurred during the cooling process to surrounding.
e. No heat generation during transportation and handling of spices in conveyer.

The considered boundary conditions as per the chosen product for simulation are as follows:

a) Initial temperature of coriander= 27^{o}C
b) Initial temperature of liquid nitrogen = -195^{o}C
c) Time of cooling =12 sec

Additionally, the physical and thermal properties with respect to moisture content were taken from previous study [26].

Solution methodology and governing equations. Heat transfer simulation of spices was done in COMSOL multi-physics software. Following were the steps for modelling –

1. Start COMSOL multi-physics and select model type (1D, 2D, 3D), Next select physics (heat transfer, heat transfer in porous etc.) and select study type (time dependent or stationary).

2. Among different options in tree of model builder, first set unit for geometry and proceed to draw geometry (Figure 1) by clicking 'build it' option to complete the process.
3. Add material and their properties by click on material or select material option according to physics selected. Provide boundary conditions by clicking on selected physics.
4. In next option i.e. mesh, two option sequence type and element size appear. In sequence type physics, controlled mesh and user controlled mesh two options appear. And are set as default. Give size and shape of mesh by clicking on user controlled type. Change mess size to fine, extra fine, finer, coarse, extra course by clicking on element size option.
5. In study option, select time dependent study, and set process parameter, physics and time of study.
6. Under result options, select the kind or form in which we want to express the result.
7. After performing all the setting steps right click on study and click on compute.

In this time dependent study, geometry of sphere was assume as sphere (Figure 1) and fine meshing was done to check the temperature distribution over each node. Boundary conditions were set to simulate the cryo-cooling. The software was used to solve the governing continuity, momentum and energy equations for the defined geometry and associated boundary conditions. The domain was defined in the global co-ordinate frame in which the solver carries out the calculations.

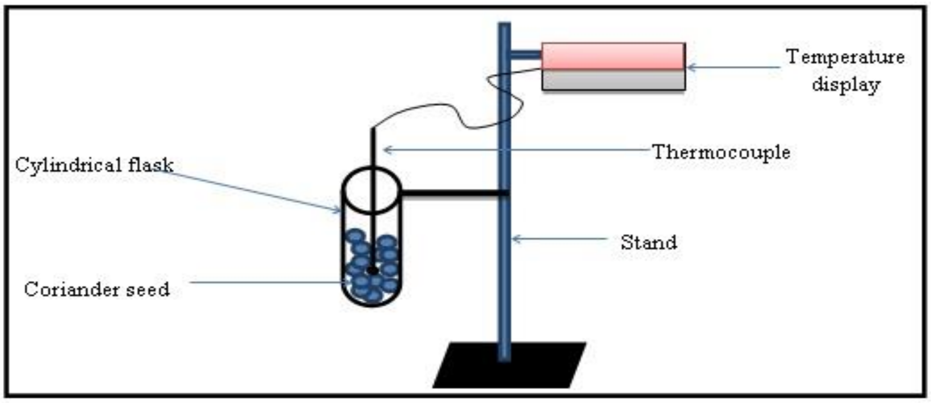


Figure 2. Experimental setup for cooling validation

a) The generalized equations for continuity, momentum and energy are as follows:
Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho V) = 0 \quad (1)$$

b) Momentum equation

$$\frac{d\rho V}{dt} + \nabla.(\rho V * V) = \nabla\left(-p\delta + \eta(\nabla V + (\nabla V)')\right) + Sm \quad (2)$$

c) Energy equation

$$\frac{\partial \rho h_t}{\partial t} - \frac{Dp}{Dt} + \nabla.(\rho V h_t) = \nabla.(k\nabla t) + S_E \quad (3)$$

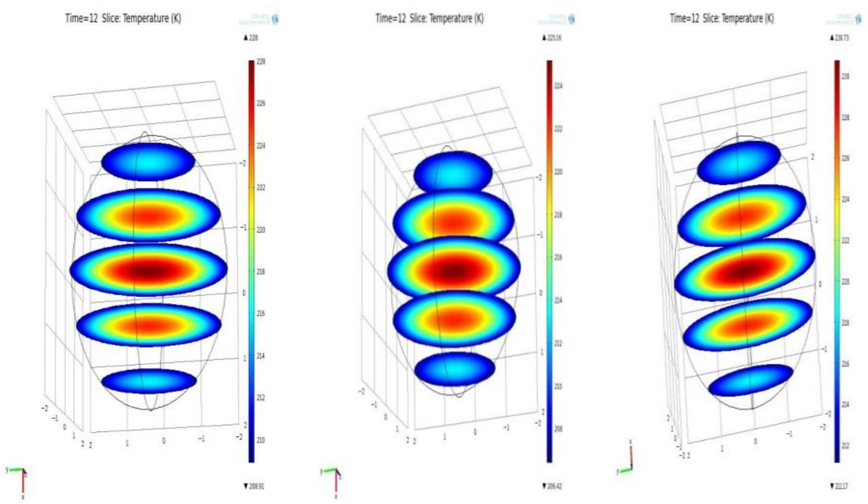
$$S_m = -\rho_{ref}\beta(T - T_{ref})g \quad (4)$$

Where, 'h total' is the specific total enthalpy expressed in terms of temperature and pressure. For the energy equation S_E is taken to be zero as there are no internal sources of energy.

Experimental verification. An experiment was carried out in a laboratory for verification of CFD simulation. Tropical cryo-cooling process was performed by direct dipping the spices in liquid nitrogen. Temperature of coriander seed was measured at time intervals of 2, 4,6,8,10,12 seconds. The experimental setup for temperature measurement is shown in fig 2. Some dipped spice seeds were taken out after certain time at defined time intervals and were filled into the tube or cylindrical flask with thermocouple. The readings of temperatures were noted down from temperature display unit.

RESULT AND DISCUSSION

The predicted temperature distribution within the spherical gain after a chilling time of 12sce can be visualised in Figure 3, which indicates that the temperature of the spice after chilling is higher at the core and decreases from the core to surface. The maximum temperature drop was found in the surface of the spices. In experimental verification we observed that the chilling rate was the highest at beginning of cooling process as the products initial temperature is 27ºC and the product temperature gradually decreased with the time. The chilling rate also decreased gradually with time and temperature of the product towards the end of chilling process.



(i): 8% w.b (ii): 10% w.b (iii): 12% w.b.

Figure3. Temperature profile of coriander seed at different moisture content

Comparison of experimental and simulation results showed better arrangement and relevance between the simulation and experimental data. Average temperature of spice seeds reduced from 27 to – 53ºC in 12 sec which shows little variation with the experimental data. Moisture present in the food grain acted as a critical factor affecting the rate of cooling. It was observed that an increase in moisture content led to a decrease in the cooling rate but increases the cooling time. Moisture present in food grain also affected the heat transfer capacity of food grain. The thermal conductivity of the coriander seed reduced with an increase in moisture content. Besides these, several factors seems to determine the accuracy of simulation. It was assumed that the geometry of spices is a regular sphere, however in reality; the sphericity value for coriander is not one [25]. Also the geometry and e shape varies with the type of grain under study and variation under assumptions may lead to prediction errors. Also, the initial temperature of spice temperature was assumed to be completely uniform in the simulation, which is very difficult to achieve in practice [12].

CONCLUSION

The CFD simulation of the cryogenic cooling of coriander seed well fitted with the data of verification experiments. It was also observed that the seed internal temperature and the chilling rate decreased with the time of cooling process. Also, higher moisture content reduces the spice thermal conductivity. Although, through CFD simulation we were able to select appropriate design values and operation conditions for developing the cryogenic cooling system for coriander seed spice but the assumptions laid for the simulation acts as a constraint in efficient applicability to other spice products. A better or developed version of software predicting the temperature at each point of product and exact geometry of seed may aid better in applying this technique. The CFD simulation model developed will prove very useful in determining design variables for during cryo cooling equipment building when cost is a major constraint factor. To achieve the more accurate result, it is suggested to take account of parameters like heat loss, heat generation during transportation and changes in the cooling media throughout the process.

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CFD SIMULACIJA HLAĐENJA SEMENA KORIJANDERA SA RAZLIČITIM SADRŽAJEM VLAGE

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Sažetak: CFD simulacija za hlađenje tokom zamrznutog mlevenja semena korijandera je izvedena da se odredi vreme zadržavanja u konvejeru. Simulirana su semena korijandera sa različitim sadržajem vlage i jednačine su rešene za definisan prostorni i vremenski domen, diskreditovan računskim mrežama i vremenskim intervalima. Rezultat simulacije pokazuje da temperatura semena korijandera opada od 27 do -53°C za 12 sec. Simulacija takođe uključuje uticaj vlažnosti na distribuciji temperature i vreme hlađenja. Numerička simulacija je dodatno potvrđena eksperimentima naglog hlađenja semena korijandera direktnim potapanjem u tečni azot.

Ključne reči: *CFD simulacija, prenos toplote, sadržaj vlage, začini*

Prijavljen: *Submitted*: 20.12.2015.
Ispravljen: *Revised*:
Prihvaćen: *Accepted*: 24.08.2016.