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Numerical Simulation of Heat and Mass Transfer Along with Shrinkages in Brinjal (Eggplant/Solonummelongena)

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Abstract: - Heat and mass transfer plays a major role in food processing. During storage of food due to environmental conditions, the food is dehydrated and leads to a loss in weight. To maintain the food quality, basically drying method is used. Food material with a high quantity of moisture content experiences shrinkage during the drying process.

The main aim of this present work was to simulate the drying shrinkage-deformation mechanism of Solonum Melongena (Eggplant/Brinjal) during the drying process. Heat and mass transfer model is coupled with structural mechanics and solved by COMSOL Multi physics tool. The mathematical model is validated by hot air drying experiment, for different temperature condition was conducted to study the heat and mass transfer along with deformations, including stresses. Temperature and moisture distribution of brinjal (eggplant) during drying were uniform, during drying material changes in shapes/dimensions. This prediction of results will help maintain the ambient conditions and preserve food quality.

Index Terms: - Stress Distribution, Deformation, Temperature and Moisture distribution, Heat and Mass Transfer, COMSOL metaphysics.

I. INTRODUCTION

Dehydration is one of the methods used commonly to improve the stability and shelf life of vegetables and fruits, since it decreases the activity of water in the material lead to reduce the microbiological activity, and minimizes the chemical and physical change during its storage. Dehydrated products are highly appreciated and accepted widely. Heat and mass transfer plays a major role in food processing. During storage of foods due to the environmental conditions, the food products are dehydrated and lead to loss of weight in a food product.

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The application of heat under suitably controlled conditions to remove the moisture content in the vegetables and fruits by evaporation process is known as drying. The hot air drying method is used as an experimental technique for validating heat and mass transfer, shrinkage-deformation with respect to different temperature and moisture concentration. Suitable model of Solonum Melongena (Brinjal/Eggplant) is selected in this work for numerical analysis. The product is subjected to a different convection drying process. Finite element analysis is used to calculate stress distribution and deformation. The samples of brinjal are selected for drying under different temperature in incubator/dryer for natural convection.

Many theories are proposed to investigate the material deformation have been conducted. Most of the research has been based on theoretical analysis.

H.R.Thomas [1] presented a paper on numerical analysis of drying induced stresses in Timber. Numerical methods for the analysis of stresses in capillary porous bodies are developed and illustrated Timber drying. In particular, the phenomenon of stress reversal is used. i.e., the surface stresses changes to compression from tension and stress at the center; tension from compression.

Kumar et al., [2] developed a mathematical model to simulate coupled heat and mass transfer during convective drying of fruit. This model can be used to predict the temperature and moisture distribution inside the fruits during drying. Two models were developed by considering shrinkage dependent and temperature-dependent moisture diffusivity. The governing equations of heat and mass transfer are solved, and a parametric study has been done with COMOSOL Multiphysics software.

Veleşcu et al., [3] the convective drying for carrots are carried out. The effective diffusivity increases as airflow rate as well as temperature increases and drying rate increases with the temperature increases and decreases with the sample diameter taken. Page's Model and Henderson & Pabis Models are used to predicting the Moisture ratio.

Azni [4] has presented to study on shrinkage and non-shrinkage model of food products during drying. A comparative study is done with and without structural change and the effect. The heat and mass equations are solved using the finite difference method.

Mayor and Sereno [5] have given a physical description of shrinkage mechanism, factors that affect the shrinkage mechanisms. Linear and Non-linearity and porosity models have been discussed. Yuan et al., [6] developed a mathematical model for apple slices where the heat-mass transfer module is coupled with the solid mechanic's module in COMSOL Software.

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The Convective drying is adapted during the process and image processing is used to predict the deformation in the apple slices.

From the literature survey, it is noticed that the moisture content has a major part in maintaining a quality of vegetables from being decayed and gets wasted. Many preservation techniques are used for food preservations such as drying, canning, salting, etc. This work investigates the study of heat and mass transfer along with shrinkage-deformation and attempted to predict stress distribution. Reduce the errors with respect to time, and The COMSOL Multiphysics software is used to improve the results.

II. MODELING

2.1. Mathematical modeling for heat and mass transfer

General Fourier's equation for conduction and Fick's diffusion equation is used to solve numerically, the heat and mass transfer with the following assumptions:

1. There is no internal heat generation in the system (i.e., Q = 0)
2. There is no chemical reaction in the system during the process.
3. Uniform initial temperature and moisture distribution along with the system
4. Only water transport is considered.
5. The product is considered as axis-symmetric while modeling.
6. The negligible velocity of air for natural convection drying process (i.e., u = 0).

Governing Equations

1. Heat transfer equation:

$$\rho . C_p . \frac{\partial T}{\partial t} = \Delta(k . \Delta T)$$

Where LHS is the time, dependent term or accumulation term and RHS is the heat transfer by conduction with the mathematical operator specifying the three-dimensional axes.

2. Mass transfer equation:

$$\frac{\partial c}{\partial t} = \nabla(D . \nabla c)$$

LHS of the mass equation is the dependent term i.e., concentration change w.r.t time, whereas RHS is the Diffusion equation.

- Initial conditions considered for the analysis of watermelon are:
  a. $\text{Initial temperature } T = T_0$
  b. $\text{Initial moisture content } M = M_0$
- For Heat transfer both convection and evaporation were considered at open boundaries.

$$n(k . \nabla T) = h_T(T_{air} - T) - h_m . \rho . (M - M_e) . \lambda$$

- Mass transfer equation at open boundaries:

$$n(D . \nabla c) = h_m(c_b - c)$$

2.2. Numerical Analysis

COMSOL Multiphysics software version 5.3a (COMOSOL Corporation, America) was implemented for solving stress and heat-mass transfer mathematical model of brinjal (eggplant). The mathematical model for the shrinkage mechanism of eggplant was solved by indirect coupling method. The heat-mass transfer mathematical model was solved and simulation by COMSOL Multiphysics software. To build a model of an eggplant. A quarter part of brinjal is considered for axis-symmetric modeling, and model is developed in UG-NX 11. The developed axis-symmetric model of the brinjal is imported to the COMSOL Multiphysics analysis tool. Predefined mesh in COMSOL tool, named Extra Fine is being used to mesh the imported axis-symmetric model. The three main physics are Heat transfer (ht), Transport of Diluted Species (tds) and Solid Mechanics (solid). Heat transfer and transport of diluted species module are added for solving of heat and mass equation to get temperature and concentration gradient, and those results are given as input to solve solid mechanics module to get required stress and deformation as output.

2.3. Experimentation

Initially, fresh brinjal (eggplant) samples are weighted individually and recorded using a digital weighing scale. Initial dimensions are measured and recorded using a digital Vernier scale. The temperature probe pierced is pierced into the sample, and the initial temperature of the sample is noted down. The incubator/dryer is set to the desired temperature and allowed to run for 30 minutes to attain constant temperature. All the weighted samples are placed inside the incubator/dryer allowed to dry. For a predetermined time interval, the samples are taken out and cooled by placing it in desiccators. After cooling samples are taken out and recorded. Experimentation is conducted to analyze the deformation in brinjal (eggplant) due to heat and mass transfer during convective drying for different parameters. Experimentation helps in visualizing the deformation behavior by a change in mass of brinjal (eggplant) for every interval. The advantage of experimentation is the high reliability of the results and outcomes. The variation in volume ratios for different ambient conditions is discussed in the following section. The samples are considered as fresh and uniform in shape.

Moisture content in brinjal (eggplant) is determined using the oven-dry method. For this, the oven is switched on and allowed to run for 15-20 minutes to attain uniform temperature. The selected fresh brinjal samples are weighed and recorded are placed inside the oven. After 60 minutes, the samples are taken out and weighed and recorded. The procedure is repeated until the two consecutive values are constant.

$$\text{Moisture Content in Percentage } (W_L) = \frac{W_b - W_a}{W_b} * 100$$

The density of brinjal(eggplant) is determined by knowing its mass and volume. The mass of brinjal can be found using a digital weighing scale. The volume of brinjal is determined using Archimedes principle which states that "The apparent weight of an object immersed in a liquid decreases by an amount equal to the weight of the volume of a liquid that it displaces."

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The volume of water displaced is equal to the volume of brinjal(eggplant).

$$\rho = \frac{m}{V}\ Kg/m^3$$

III. RESULTS AND DISCUSSION

3.1 Natural Convection drying for full brinjal at temperature 45°C.

Full brinjal sample is considered an initial parameter recorded during experimentation.

Initial Temperature of Brinjal (T_i) = 31.4°
Relative humidity inside dryer = 9.2 %
Number of samples = 30 (3 per interval)
Drying time in hours = 72 hrs
Dryer temperature = 45°C

3.1.1 Moisture Distribution

Percentage variation of moisture concentration between numerical and experimental are calculated and are tabulated in Table 3.1.

Table 3.1: Moisture distribution for natural convective drying.

Time (in hrs)	Experimental (E)	Numerical (N)	% Error E v/s N
0	29072.33	29072.33	0.00
1	28755.11	28627.3	0.44
2.5	28271.78	27981.8	1.03
4	27788.44	27358.9	1.55
19	22955.11	22210.2	3.25
22	21988.44	21373.1	2.80
24	21344	20829.5	2.41
27.5	20216.22	19934.9	1.39
43	15221.78	16733.1	9.93
48	14725.56	15882.3	7.86
72	12328.22	12776.4	3.64

It is noticed that the percentage of error between experimental and numerical results are between the ranges of a minimum of 0.44% to 9.93%. The possible reason for this variation in results is due to ambient conditions and physical parameters of brinjal. As the time increase, the moisture reduces rapidly.

3.1.2 Deformation (Volume Ratios)

Percentage variation of volume ratios (deformation occurred during drying) between numerical and experimental are calculated and are tabulated in Table 3.2.

Table 3.2: Volume Ratio for natural convective drying.

Time (in hrs)	Experimental (E)	Numerical (N)	% Error E v/s N
0	1	1	0.00
1	0.970853	0.98608	1.57
2.5	0.966132	0.96601	0.01
4	0.944694	0.9467	0.21
19	0.825927	0.78663	4.76
22	0.78996	0.76053	3.73
24	0.750544	0.74404	0.87
27.5	0.746321	0.71679	3.96
43	0.688126	0.61701	10.33
48	0.554565	0.59082	6.54
72	0.480201	0.4943	2.94

It is noticed that the percentage of error between experimental and numerical results are between the ranges of a minimum of 0.01% to 10.33%. The possible reason for these variations in results is due to ambient conditions and physical parameters of brinjal. The volume ratio reduced by 50 % after 72 hours of drying.

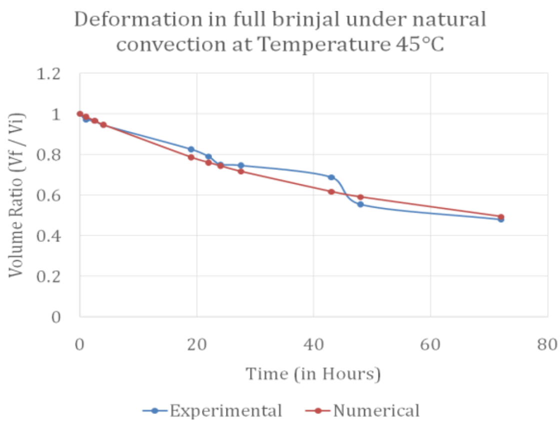

Fig. 3.1 Graph showing the deformation of full brinjal under natural convection at temperature 45 0 C.

3.2 Natural Convection drying for sliced brinjal at temperature 40°C.

The brinjal is sliced across its length, and initial parameters and dimensions are recorded.

Initial Temperature of Brinjal (T_i) = 28.20°
Relative humidity inside dryer = 10.7 %
Number of samples = 15 (3 per interval)
Drying time in hours = 22.5 hrs
Dryer temperature = 40°C

3.2.1 Moisture Distribution

Percentage variation of moisture concentration between numerical and experimental are calculated and are tabulated in Table 3.3.

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Table 3.3: Moisture distribution for natural convective drying.

Time (in hrs)	Experimental (E)	Numerical (N)	% Error E v/s N
0	29077.33	29077	0.00
1	25626.33	25536	0.35
3	19410.67	20680	6.54
4.5	14587	14452	0.93
20.5	99.88889	96.89	3.00
22.5	38.66667	35.33	8.63

It is noticed that the percentage of error between experimental and numerical results are between the ranges of a minimum of 0.35% to 8.63%. The possible reason for these variations in results is due to ambient conditions and physical parameters of brinjal.

3.2.2 Deformation (Volume Ratios)

Percentage variation of volume ratio between numerical and experimental are calculated and are tabulated in Table 3.4.

Table 3.4: Volume Ratio for natural convective drying.

Time (in hrs)	Experimental (E)	Numerical (N)	% Error E v/s N
0	1	1	0.00
1	0.893882	0.8741	2.21
3	0.701992	0.723	2.99
4.5	0.556132	0.5315	4.43
20.5	0.096065	0.0882	8.19
22.5	0.081011	0.082	1.22

It is noticed that the percentage of error between experimental and numerical results are between the ranges of a minimum of 1.22% to 8.19%. The possible reason for these variations in results is due to ambient conditions and physical parameters of brinjal.

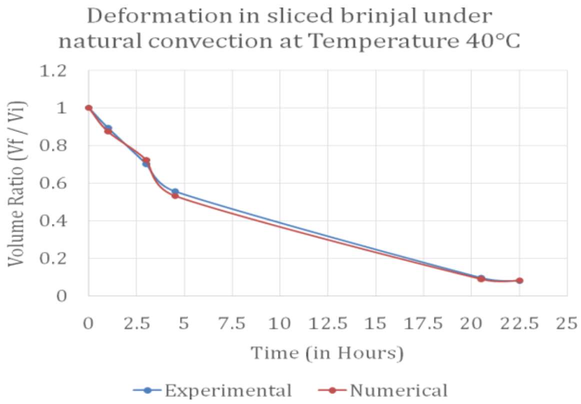

Fig. 3.2 Graph showing the deformation of full brinjal under natural convection at temperature 40 0 C.

3.3. Stress Distribution

Natural convective drying of brinjal(eggplant) at a drying temperature of 45°C is conducted for 72 hours. Fig. 3.5 shows the drying stress curve during natural convective drying. Fig. 3.3, and Fig. 3.4 show the axis-symmetric model of brinjal. Which shows the stress distribution before and after drying for 72 hours under natural convective drying process.

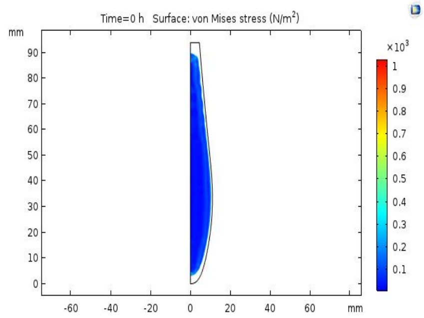

Fig. 3.3: Axis-symmetric model of brinjal showing stress distribution before drying under natural convection.

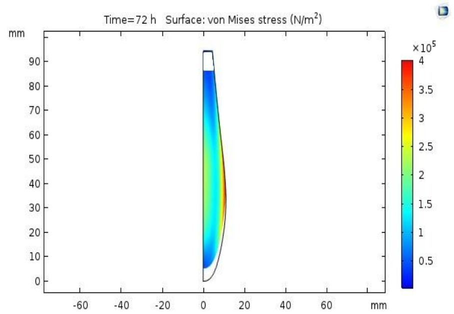

Fig. 3.4: Axis-symmetric model of brinjal showing stress distribution after drying for 72 hours under natural convection.

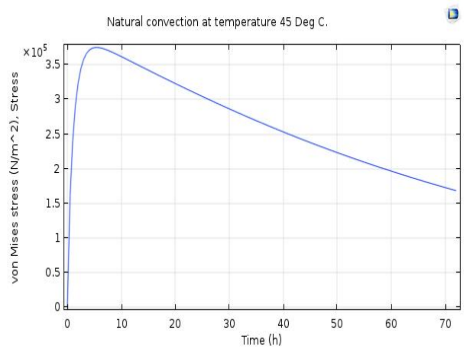

Fig. 3.5: Graph showing the stress distribution in brinjal under natural convective drying at temperature 45°C.

Initially, the curve increases due to higher moisture concentration as more drying stress are required. For a drying time of 5 hours 30 minutes, the value of drying stress reaches a maximum of 3.75*105 Pa. At 10 hours of the time, the moisture concentration decreases to 3.4*105 Pa. It indicates that the dying time increase the moisture concentration reduces Gradually thus drying stress reduces simultaneously. After 72 hours of drying the stress reaches 1.68*105 Pa with the 50% reduction in moisture content. This indicates that the moisture content plays a major role in drying and deformations.

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3.3.1 Stress distribution in sliced.

The model of sliced brinjal (eggplant) as shown in the fig.3.6. And 3.7 shows the stress distribution in sliced brinjal (eggplant). The time considered for stress distribution in the sliced brinjal (eggplant) is a maximum of 22.5 hours as the stresses decrease rapidly with time.

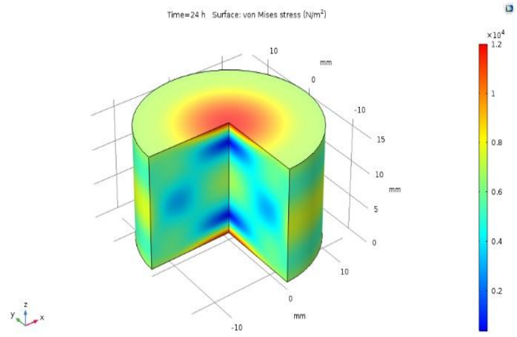

Fig. 3.6: Sliced brinjal before drying under natural convection

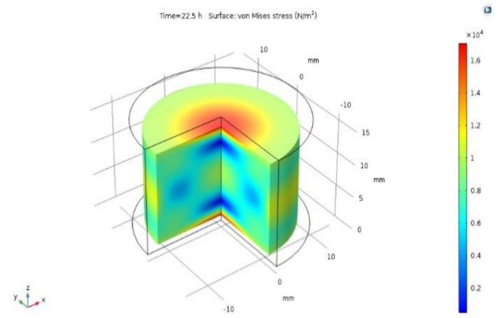

Fig.3.7: Stress distribution in sliced brinjal after 22.5 hours of drying.

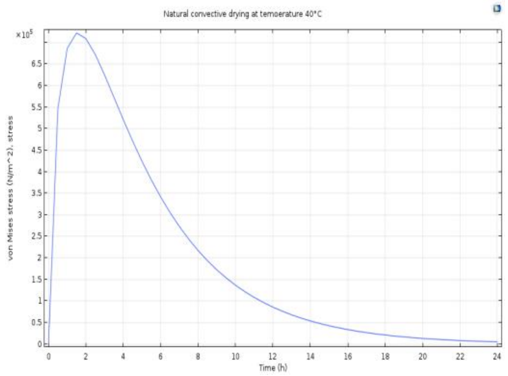

Fig. 3.8: Stress distribution curve of sliced brinjal under natural convective drying.

The stress curve during the drying process is shown in Fig. 3.8. The maximum value of drying stress is 7.3*105 Pa occurred after drying for 1.5 hours. As moisture content reduces after 1.5 hours, the drying stress gradually decreases and reaches 0.24 Pa after 22.5 hours of drying. Due to zero moisture content in brinjal, the required drying stresses reach to 0 Pa.

IV. CONCLUSION

In this study, the heat-mass transfer, coupled with the shrinkage-deformation mathematical model, was applied to predict for hot air drying for natural convection for eggplant (brinjal) predict shrinkage-deformation of brinjal and sliced brinjal. Successful experimentation of convective drying on brinjal(eggplant) for the different parameters along with deformation behaviors. From the experimentation, the density of brinjal is found to be 580 kg/m3 by applying Archimedes Principle. From the experimentation, the average moisture content present in brinjal is found to be 90.24%. For natural convective drying at temperature 45°C, the experimental value of moisture content ranges from 90.24% to 38.26%, and numerical results vary between 90.24% and 39.65%. The percentage error ranges from 1.03% to 9.93%. For sliced brinjal under natural convective drying at temperature 40°C, the experimental value of moisture content ranges from 90.24% to 0.12% and numerical results vary between 90.24% and 0.11%. The percentage error ranges from 0.35% to 8.63%. For natural convective drying at temperature 45°C, the experimental value of deformation ranges from 1 to 0.48, and numerical results vary between 1 and 0.4943. The percentage error ranges from 0.01% to 10.33%. For sliced brinjal under natural convective drying at temperature 40°C, the experimental value of deformation ranges from 1 to 0.081, and numerical results vary between 1 and 0.082. The percentage error ranges from 1.22% to 8.19%. The peak stress for the natural convective drying at temperature 45°C is 3.75*105 Pa. The peak value of stress occurred after 1.5 hours of drying. Stress results indicate the deformation in brinjal depends on temperature, moisture content and air velocity. The results was in good agreement with the experimental results.

REFERENCES

1. H.R. Thomas 1983, "Numerical analysis of drying induced stress in Timber: An Orthootropc model". Mechanics of materials. Volume 2 (Issue 3) 249-263. doi.org/10.1016/0167-6636 (83)90019-4.
2. Chandan Kumar, Azharul Karim, Mohammad U.H.Joardder, Graeme J. Miller, 2012, "Modelling Heat and Mass Transfer Process during Convection Drying of Fruit". The 4th International Conference on Computational Methods (ICCM2012). www.researchgate.net/publication/252629843 (www.ICCM-2012.org).
3. Md Mahiuddin, Md. Imran H Khan, C.Kumar, M.M. Rahman and M.A.Karim, 2018, "Shrinkage of food materials during drying: Current status and challenges". Comprehensive reviews in Food science and Food safety. Volume 17 (Issue 5) 1113-1126. doi.org/10.1111/1541-4337.12375.
4. Marcin BlazniakAndreasen, 2009, "Modelling of Heat and Mass Transfer in Food Products", Excerpt from the Proceedings of the COMSOL Conference, https://www.researchgate.net/publication/268205378
5. IonuţDumitruVeleşcu, IoanŢenu, PetruCârlescu, VasileDobre, 2013, "Convective Air Drying Characteristics for Thin Layer Carrots", Food Science and Technology, Volume 70 (Issue 2) 129-136, www.researchgate.net/publication/307649171.
6. Nor AzniShahari,2012, Mathematical modelling of drying food products: Application to tropical fruits,www.researchgate.net/publication/294583779.
7. L. Mayor, A.M. Sereno, 2004, "Modelling shrinkage during convective drying of food materials: a review". Journal of Food Engineering. Volume 61 (Issue 3) 373-386. doi.org/10.1016/S0260-8774 (03)00144-4.
8. Yuejin Yuan, Libin Tan, Yingying Xu, Yueding Yuan, Jixian Dong, 2019, "Numerical and experimental study on drying shrinkage-deformation of apple slices during process of heat and mass transfer". International Journal of Thermal Sciences. Volume 136 (Issue 1) 539-548. doi.org/10.1016/j.ijthermalsci.2018.10.042

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