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Simulation of Microwave Assisted Finish Drying and Inactivation of Escherichia Coli, Bacillus Cereus and Staphylococcus Aureus of Onion Powder

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Abstract: *The onion powder with initial moisture content of 10% (db) in form of thin infinite layer of thickness 5mm was dried using a laboratory microwave oven at 50W/g microwave power density to final moisture content of 2% (db).The temperature, moisture change pattern of the experimental process was monitored. Computer simulation of the predicted temperature pattern with drying time was obtained by using the mathematical model governed by energy balance equation and using data of the thermo-physical properties of the onion powder obtained either experimentally or through literature review. The usage of high microwave power to mass ratio results in raised temperature with reduced drying time. The decrease in drying rate is due to initial moisture content. Effective moisture diffusivity increases with decreasing moisture content due to the application of high power density. Lethality values for Escherichia coli, Bacillus cereus spores and Staphylococcus aureus, which are more prominent in onion powder, were then evaluated from the simulated temperature curve. DT and z values were used to estimate the sterilization values for each individual microorganism. It was observed that significant sterilization of E.coli and S.aureus start after 35 s at a minimum temperature of 89oC with 0.047 and 0.044 log reduction while, for B.cereus it starts after 75 s at 117oC with 0.431 log reduction. The maximum temperature of 117°C was limited due to unacceptable sensory quality of end product.*

Keywords : *Lethality, Escherichia coli, Bacillus cereus, Staphylococcus aureus, Effective moisture diffusivity .*

I. INTRODUCTION

India with only 16% of world area and 10% of world production is the second largest producer of onion (Allium cepa). They are relatively high in energy, rich in calcium, riboflavin, moisture and flavonoids. Flavonoids are important bioactive compounds responsible for aroma and distinct flavor, and have potential health benefits [1]. Heating of vegetable products lead to thermal degradation,

oxidation and leaching of flavonoids. Onion powder when heated to temperature above 120^{o}C, loses its important flavonoids compounds (quercetin and glycosides) and sugar content. Since, onions have a short shelf life and the post-harvest loss in India is very high due to insufficient storage units, drying or dehydration of onions is found to be most suitable method for increasing its shelf life [2].

Hot air drying is the preservation method for foods but drying with hot air has a low efficiency in terms of large processing time and quality of end product. Residual sugar in onion are affected by air velocity and relative humidity in hot air drying, whereas in case of microwave drying residual sugar is not affected by any process parameter. Hence, microwave heating have become a common and popular source of cooking foods in most developed countries. Heating of onion powder for finish drying or sterilization using hot air requires a long processing time which results in heavy contamination of product along the processing line. Therefore, the application of microwave energy for sterilization process can be a smart alternative with minimum processing time [3]. Keeping in view the importance of microwave processor for industrial sterilization purpose and the limitations of the traditional processes, the present research was undertaken to develop and validate temperature profile during microwave finish drying of onion powder and estimate lethal effects of the microwave drying process on *E. coli, B. cereus* and *S. aureus.*

II. MATERIALS AND METHODS

A. Raw Material preparation

Dried onion flakes of white welsh onion procured from Jain Irrigation Private Limited, Jalgaon and then pulverized using a grinder. The powdered sample was then sieved to maintain an average particle size of 0.710 mm for around 70% of the grounded sample. For determination of initial moisture content, 2-3 g of powdered onion sample was taken in petri-dishes and dried using vacuum oven at 70^{o}C until insignificant weight change was obtained [4,5].

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B. Determination of actual power

The drying was carried in a domestic microwave oven (Samsung, 2450GHz) with maximum output of 800W. The actual microwave power output was determined by International Microwave Power Institute (IMPI) 2-L test method. The power measurement repeated for three times and following empirical equation was used to estimate the actual microwave output power [6]:

$$P = \frac{4.187M_w(T_2 - T_1) + 0.55M_c(T_2 - T_0)}{t}$$

Where P= Power output(W); M_w= mass of water(g); M_C =mass of container (g); T_2 = final temperature in °C; T_1= initial temperature in °C; T_0 = ambient temperature in °C; t is time (s)

C. Mathematical Modeling of Heat and Mass Transfer by Microwave Assisted Drying

The predicted heat, moisture transfer is vital for proper equipment design, process optimization improvement of final product quality. Heat transfer and temperature profile within the product [7]

$$\frac{\partial T}{\partial t} = \propto \nabla^2 T + \frac{Q}{\rho C_p} + \frac{Q}{\rho C_p}\frac{\partial(M \times H)}{\partial t}$$

Where T = product temperature, t = time, Q = conversion of microwave energy per unit volume, M = moisture concentration, H = enthalpy, thermal diffusivity, density and specific heat. Conversion of electromagnetic energy in to heat energy generates heat per unit volume of material (Q). Its relationship with the average electric field intensity (E_{rms}) is derived from Maxwell's equations of electromagnetic wave [8]. The microwave heat generation term per unit volume can be written as

$$Q = 2\pi f \,\epsilon_0' \epsilon'' \, E_{rms}^2$$

Where, f = frequency, ϵ_0' = dielectric constant, ϵ'' = food factor loss, E_{rms}^2 = Average electric field intensity. The surface of product being heated by microwave energy has typically convection phenomenon-either natural or forced convection,

$$k_t \frac{\partial T(t)}{\partial z} = h(T - T_0) + m_w \lambda_w + \sigma_{rad}\, \epsilon_{rad}\, T^4 - \alpha q_{rad}, Z = 0$$

Where, T = load surface temperature, z = normal to surface, h = convective heat transfer coefficient, m_w = evaporation rate, λ_w = latent heat vaporization, σ_{rad} = Stefan boltzman constant, ϵ_{rad}= radiative surface emissivity of load, q_{rad}= radiant heat flow rate per unit surface area, α =surface absorptivity

A Fick's second law of diffusion was taken into consideration for evaluation of moisture transport in food material during the analysis of falling rate period, which is given by [9,10]

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial x}\left(D \frac{\partial M}{\partial x}\right)$$

Where, M = free moisture content, kg water/kg dry matter; t= time, sec; x =diffusion path or length, cm; and D = moisture diffusivity, $cm^2 s^{-1}$ A considerable variation in diffusivity with the method of slopes technique is used for the estimation of effective moisture diffusivity of thin infinite onion slab at varying moisture content under different drying conditions.

For a thin infinite slab being dried from only one side, the following assumptions were made:

- Initial moisture is uniformly distributed.
- The surface moisture content of the sample reaches equilibrium with the surrounding air condition.
- At the surface negligible resistance to mass transfer.
- Diffusion mechanism is used for representation of mass transfer.
- For an infinite slab, long drying time

D. Estimation of thermal properties of onion powder, *Specific heat (C_p)*

It is defined as amount of heat needed to raised the temperature of unit mass by 1°C. It is determined by using following equation,

$$C_p = C_{po}(1 - X) + C_{pw}X$$

Where, Cp = Specific heat, C_{po}= Specific heat of dry matter (solid), C_{pw} = Specific heat of water, X = moisture content of product.

E. Determination of bulk density (ρ)

The determination of loose bulk density was done by freely pouring a known amount of the powder sample into a 10 ml graduated cylinder, the volume of sample is noted to calculate the bulk density.

$$\rho = \frac{m}{\frac{(\pi D_b^2 h_b)}{4}}$$

m = mass of the sample (g); D=diameter of the cylinder (cm) and h_b is the height of the sample in the cylinder (cm).

F. Microwave profile of onion powder

Onion powder with a thickness of 0.5 cm, the bulk density of 0.355 $g / cm3$ and initial moisture content of 9.63% (wet basis) was heated under microwave power with a set power density of 50W / g for a total heating period of 80 s and temperature measurement being done at every 10 s of the time interval with a digital infrared thermometer [11]. The same experiment was repeated and the sample weights were measured at similar intervals when the oven turned off periodically. Moisture content determination was done from the initial, transient weights of the samples and its initial moisture content.

G. Prediction of lethality value (F) and Sterilization value (SV) for Escherichia coli, Bacillus cereus and Staphylococcus aureus

The prediction of lethality value (F) was done by using the relationship between temperature and z value given in the literature by [12,13]

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$$F = \sum_{o}^{t} dt \times 10^{(T-121.1)/z}$$

Where T = temperature at any instant (°C); dt is the time interval (s); t = total time of heating (min); z is the characteristic constant for a particular micro-organism.

$$D_T = D_{T'} \times \frac{10^{(121.1-T)/z}}{10^{(121.1-T')/z}}$$

$$SV = \frac{F}{D_T}$$

The prediction of sterilization value (SV) was done by first calculating the value , where T = temperature at which the lethality value is calculated. The empirical relation for calculating, D_T is the decimal reduction time at given temperature (min).

III. RESULTS AND DISCUSSION

A. Validation of mathematical model and analysis of temperature profile during microwave drying of thin infinite onion slab

It is validated by comparing the numerical solution with temperature profile of experimental data of onion powder obtained during the 1-D heat, mass transfer in the laboratory. It was observed that the temperature changes predicted during microwave heating from the model is in line with experimental data [14]. The average error between experimental, temperature data was around 3%. Table I decimal reduction time and z values of different microorganisms present in dry onion powder sample, Table II represent the properties of material taken for simulation or determined during modeling and simulation.

Table I:The decimal reduction time and z values of different microorganisms present in dry onion powder sample (Beuchat *et al.*,2011)

Pathogens	D Values	Z values
Bacillus cereus spores	D_{95}=(1.2-36) min	z=7.9-9.9°C
Escherichia coli (0157:H7)	D_{63}=0.5 min	z =6 °C
Staphylococcus aureus	D_{60}=(1-2.5) min	8-10 °C

Table II: Material properties used during the simulation

Properties	Values	Units	Source
λ	2257	kJ/kg	Saturated steam table
h	0.00317	W/cm^2 K	Determined
M_{vo}	0.273x10^{-3}	g/cm^3	Saturated steam table
$M_{v\infty}$	0.272x10^{-3}	g/cm^3	Saturated steam table
plo	0.625	W/cm^3	Determined
C_P	1.276	J/g.K	From Eq.
C_{PW}	4.18	J/g.K	Lu et al.,1999
T_o	28	^{0}c	Measured
T_i	41.5	^{0}c	Measured
ρ	0.355	g/cm^3	Measured
1	0.5	Cm	Measured

The graph between average temperature and time (Fig 1) at 50 W/g concluded that the predicted and actual values for the temperature are significantly close to each other and only during 40-50min of drying the values are having little mismatching otherwise model fit is high [15, 18].

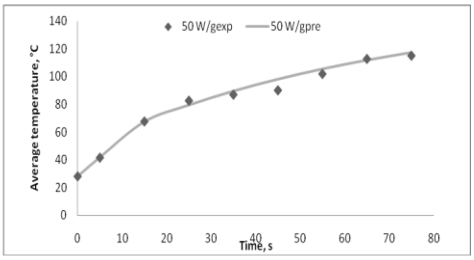

Fig 1: Predicted and actual values for average temperature during frying time.

Assessment of drying rate and product temperature:
From curve it is observed that drying rate follows a non-linear relationship with the moisture content (db) . Moisture content to effective moisture diffusivity:

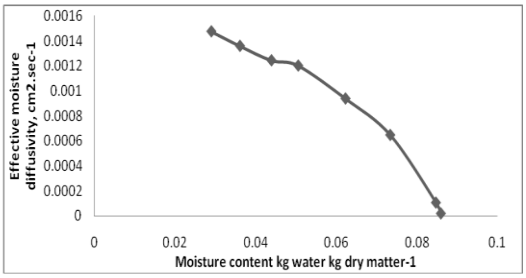

Fig 2:

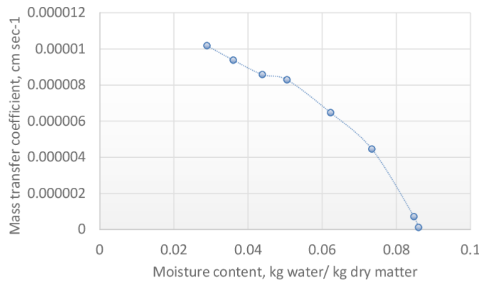

Fig 3:

It is observed that the D values increases with decrease in moisture content.Assessment of thermal death time or lethality and sterilization values for different micro organisms present in the onion sample were done (refer figure 3-6)

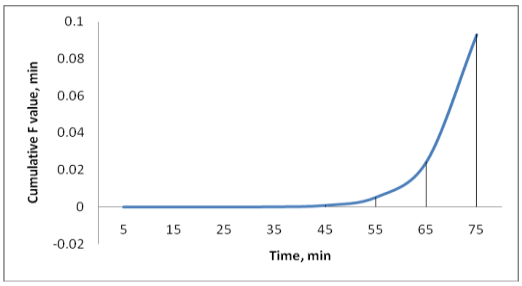

Fig 4:

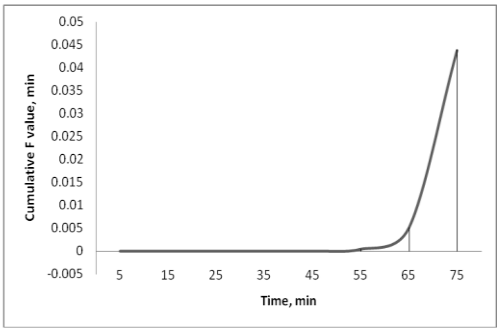

Fig 5:

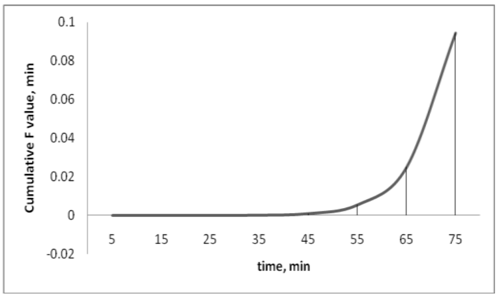

Fig 6:

From the curves, it can be observed that the lethality value F or thermal death time for *S.aureus* was the greatest with 0.094 min, followed by *B.cereus* spores with 0.093 min and *E.coli* with the lowest value of 0.043 min. The value of D_T for *S.aureus*, *B.cereus* spores and *E.coli* was found to be 4.9 X 10^{-6} min, 0.215 min and $5X10^{-10}$ min respectively. The large sterilization values of *E.coli* (coliform) and *S. aureus* is due to very small D_T values of the mentioned pathogens at temperatures much lower than the temperature reached due to experimental process or numerical modeling. However, the low sterilization value of *B.cereus* spores is because of its large value at temperature lower than predicted temperature from heating.

IV. CONCLUSION

A simplified numerical model used for the computer simulation described the changes in the temperature pattern of onion powder observed during experimental microwave drying process. The usage of high power to mass ratio increases temperature,heat transfer coefficient and reduces drying time along with an increasing trend of effective moisture diffusivity with time. The sterilization of E. coli and S. aureus starts after 35 s at a minimum temperature of 89°C while, for B. cereus it starts after 75 s at 117°C. The drying of the onion powder cannot be performed at higher power density and longer times as it leads to very high-temperature rise which in turn results in product charring. Hence, the complete inactivation of bacillus cereus spores is not possible during this process to maintain the quality of finish dried product.

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