The thermo-pack equipment and its evaluation for measuring temperature of material during hot air puffing of rice-soy cold extrudate

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Received : 17.02.2014; **Revised :** 09.03.2014; **Accepted :** 21.03.2014

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ABSTRACT : The thermo-pack equipment was developed and used to measure temperature of rice-soy cold extrudate during hot air puffing. The theoretically calculated and experimentally obtained co-efficients of equation for temperature ratio with puffing time were close enough to show that the method and equipment used for measurement of product temperature during hot air puffing were appropriate with fairely high correlation co-efficients at all the temperatures as 200 to 240^{0}C during puffing. During puffing time upto 10 to 15 s, the predicted product temperatures were highly deviating from experimentally measured product temperatures indicating phase of initiation of puffing. Thus, theoretical equations of temperature ratio with puffing time adopted for measuring surface, average and centre temperature of puffing material during hot air puffing are well acceptable.

KEY WORDS : Puffing, Temperature, Thermo-pack, RTE foods

HOW TO CITE THIS PAPER : Pardeshi, I.L. and Chattopadhyay, P.K. (2014). The thermo-pack equipment and its evaluation for measuring temperature of material during hot air puffing of rice-soy cold extrudate. *Internat. J. Agric. Engg.*, **7**(1) : 212-216.

The ready-to-eat (RTE) foods are convenient foods and prepared using different processes like hot extrusion, baking, toasting, roasting and puffing as oil puffing, sand puffing, gun puffing, hot air puffing, microwave puffing, etc. The hot air puffing of rice (Chandrashekhar and Chattopadhyay, 1989), potato cubes (Mukherjee, 1997), freeze thaw dried potato cubes (Khodke, 2002), potato powder based cold extrudates (Nath and Chattopadhyay, 2007), rice-soy based cold extrudates (Pardeshi, 2008), wheat-soy based cold extrudates (Pardeshi and Chattopadhya, 2010), tapioca-pea nut based cold extrudates (Yewale and Chattopadhyay, 2013), fryums (Babar, 2010) have been found to be carried out by different researchers. The meager literature is available on heat transfer studies during hot air puffing. Chandrashekhar and Chattopadhyay (1989) conducted heat transfer study during pneumatic puffing of rice. They had calculated the surface, centre and average temperature of puffing product theoretically following theory stated by Carslaw and Jaeger (1959) and Loncin and Merson (1979). These studies were helpful to know the time and temperature of puffing at which the puffing initiates and completes. However, to verify the feasibility of application of these theories, the practical measurement of temperature of puffing product is needed.

Chandrasekhar and Chattopadhyay (1989) measured temperature of rice puffing in fluidized bed air puffing system. For this, the pre-conditioned rice kernels (cv. PANLOI) were puffed in the puffing machine at a puffing air temperature of 250^0 C and the puffed kernels were collected in a thermo-pack kept close to the cyclone separator outlet. Their temperature was immediately measured with the help of digital thermometer. The same technique was thought adopt for measuring temperature of product getting puffed in whirling bed hot air puffing column.

Mukherjee (1997) measured the temperature of the potato cubes puffing in HTST air puffing system. He used 26 gauge iron-constantan thermocouple connected to a six channel digital temperature indicator of range 0-400^{0}C. The thermocouple tips were inserted inside the puffing cylinder at the inlet and outlet (at the maximum height of the bed) points through 0.8 mm holes drilled in the puffing column. The tips of the thermocouples were kept inside 1 mm inner dia, open end glass tubes of 5 mm length. This prevented the thermocouples from radiation, permitting it to register air temperature only. For measurement of centre temperature of the material, the tip of the thermocouple was inserted at the centre of a cube which was held suspended inside the expanded bed of materials thus allowing free movement. The surface temperature of the material was determined by fixing the thermocouple tip on the surface of the cube with the help of small clipping arrangement and the cube being held in the expanded bed.

The experimentally measured surface, average and centre temperature of puffing material could be verified by the theoretically deduced equations to the form $TR = Ae^{-K_H t}$. The values of A and K_H were calculated theoretically and verified with experimentally determined one by Chandrasekhar and Chattopadhyay (1989) for puffing rice and Mukherjee (1997) for puffing potato cubes.

Sandhu and Singh (1983) measured average temperature rice sample during drying using thermocouples. Pardeshi *et al.* (2008) also adopted thermocouples to measure temperature of green peas kernels during drying and utilized for heat transfer studies during drying.

■ METHODOLOGY

Experimental set up and material selection:

An experimental set up of batch type whirling bed hot air puffing developed by Mukherejee (1997) was used to carry out puffing of cold extrudates prepared from rice-soy (92.5:7.5) flour using Dolly Mini P3 pasta machine as suggested by Pardeshi (2008).

The product taken for puffing in the present study is initially a flat shaped strip. It is getting puffed along the walls due to internal vapour pressure built up. This keeps the product hollow from inside. The prominent expansion could be observed only along thickness of product. The length and breadth of product were seen to be unaltered during puffing. The puffing was carried out with hot air at different temperatures of 200 to 240^{0}C.

Measurement of temperature of product:

The temperature at inlet and outlet of puffing column of the whirling bed hot air puffing system developed by Mukherjee (1997) was measured by 26 gauge iron-constantan thermocouple connected to a six channel temperature indicator of range (0-400°C). The thermocouple joints at the cold end were perfectly insulated with glass tape. The thermocouple tips were inserted inside the puffing chamber at the inlet and outlet (at maximum height of bed) points through 0.8 mm holes drilled in the puffing column. The tips of thermocouples were kept inside 1 mm inner dia, open end glass tubes of 5 mm length (Mukherjee, 1997). This prevented the thermocouples from radiation, permitting it to register the air temperature only.

For measurement of average temperature of material, the highly insulated thermo-pack was prepared in the laboratory as shown in Fig. A. This had provision for receiving the product coming out of the puffing system and closing the insulating cover immediately. The hot product collected into the bulb, was coming in contact with thermocouple inserted into it. Initially the temperature was increasing for 3-4 seconds and getting reduced thereafter. The maximum temperature indicated was recorded as temperature of product. Though the time required for the product to come out of puffing chamber, get received into the conical hopper and discharged into the bulb of thermo-pack and closing of thermo-pack is very short *i.e.*, about 2 to 3 s, there is possibility that the product may loose some heat to surrounding. Thus the temperature recorded by this instrument may be comparatively less than actual one. Therefore, this instrument was first calibrated for the actual temperature of product and temperature noted by this instrument. For this purpose, puffed product was kept into the oven toasting machine till it attained temperature between 65 to 200°C. This temperature was noted using iron-constantan thermocouple, kept in contact with mass of heating material, shown by digital temperature indicator. After noting the actual temperature of product, the product was immediately taken out of oven and fed into the bulb of thermo-pack and closed it. This took nearly 1 to 2 s of time. The digital temperature indicator showed that the temperature increased initially (for 3 to 4 s) and then decreased. Therefore, the maximum notable temperature was read as temperature of product. This indicated that there was difference between these corresponding actual and noted temperatures. Fig. B shows the relation between actual temperature and temperature noted by the thermo-pack instrument. This shows that the difference was higher at higher temperatures and gradually decreased with lowering down of product temperature. This may be due

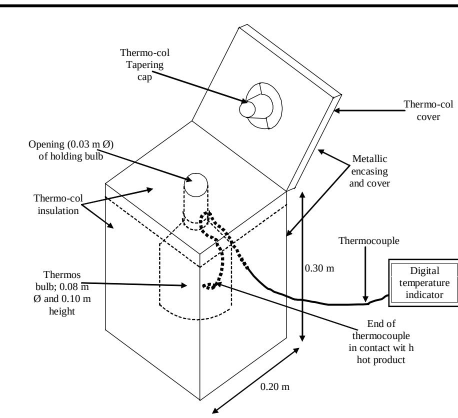

Fig. A : Thermo-pack prepared for measurement of average temperature of puffing product

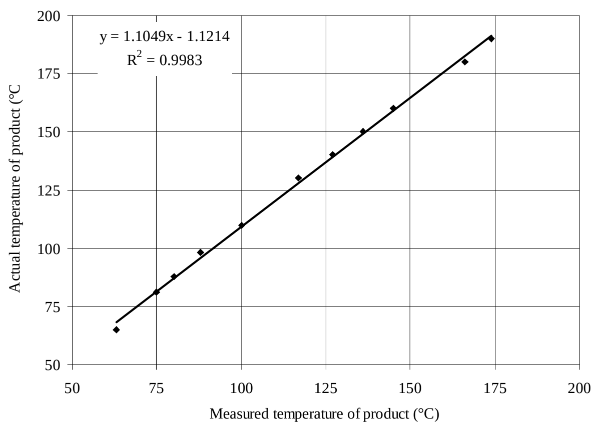

Fig. B : Calibration chart for reading actual temperature of product from temperature measured using thermo-pack

to the fact that at higher temperature, due to higher temperature gradients, the loss of heat would be more as compared to that at lower temperatures.

From Fig. B, the relation between noted temperature (x) and actual temperature (y) of the product was developed and is given below :

$$\mathbf{y = 1.049\,x - 1.1214 \qquad (R^2 = 0.9983)} \qquad (1)$$

This equation could be used for calibration purpose. The noted temperature of product was converted using above Eq. 1, in order to obtain actual temperature of puffing product at given interval of time. Each experiment was replicated five times.

The experimentally determined average temperature of product could be used for heat transfer study during hot air puffing.

Theoretical estimation of material temperature during puffing:

The equation for prediction of temperature at any point in a semi-infinite slab can be considered for present case and it can be expressed in the following form (Carslaw and Jaegar, 1959).

$$\text{Temperature ratio, TR} = \frac{T_a - T_{(t)}}{T_a - T_{(0)}} = 4L_c \sum_{n=1}^{\infty} \frac{J_1(C_n)}{C_n (C_n^2 + L_c^2 J_0(C_n))} \exp^{\frac{-C_n^2 \alpha t}{a_p^2}} \qquad (2)$$

where,

T_a = Air temperature (assumed to be constant), °C

$T_{(0)}$ and $T_{(t)}$ = Temperature of material as initial at time 0 and after puffing time of t (s), respectively.

L_c = Biot's number $h' a_p / k_p$

a_p = Equivalent radius, 0.25 (l' + t'), m

C_n : n = 1,2,3, …. are the roots of the equation, $C_n J_1(C_n) = L_c J_0(C_n)$

$J_0(C_n)$ and $J_1(C_n)$ are, respectively the Bessel functions of C of order 0 and 1.

Simplifying the Eq. 2, by neglecting higher terms, we get

$$\frac{T_a - T_{(t)}}{T_a - T_{(0)}} = 4L_c \frac{J_1(C_1)}{C_1 (C_1^2 + L_c^2) J_0(C_1)} \exp^{\frac{-C_1^2 \alpha t}{a_p^2}} \qquad (3)$$

$J_0(C_1)$ and $J_1(C_1)$ are, respectively the Bessel functions (first root) of C of order 0 and 1. The values L_c, C_1, $J_0(C_1)$ and $J_1(C_1)$ were read from the standard tables for Bessel functions (Carslaw and Jaegar, 1959, Loncin and Merson, 1982, Das, 2005) and used for further calculations.

The equation was derived taking into consideration, the assumption that the air temperature did not change between the inlet and outlet and with time whereas the material temperature varied with time. In the present study it was observed that the variation in air temperature was comparatively less than variation in temperature of puffing product, which justified the suitability of this equation.

From Eq. 3, the simplified relationship can be established as

$$TR = Ae^{-K_H t} \qquad (4)$$

where,

$$A = 4L_c \frac{J_1(C_1)}{C_1 (C_1^2 + L_c^2) J_0(C_1)} \text{ and } K_H = \frac{-C_1^2 \alpha}{a_p^2}$$

In order to determine theoretical co-efficients of Eq. 4, the requisite product properties like thermal conductivity, specific heat and thermal diffusivity of puffing material were determined at average product temperature (Das, 2005) using empirical equations given by Choi and Okos (1986) and Singh and Heldman (2001).

■ RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Material temperature during puffing of rice-soy snack foods:

For the HTST air puffing of rice-soy snack foods, the inlet and outlet air temperature in puffing column measured using copper-constant thermocouples and average product temperature measured as discussed above and shown Fig. 1. The theoretical average temperature of puffing product was estimated as discussed above by estimating the theoretical co-efficients of Eq. 4.

The experimental co-efficients of Eq. 4 were determined by plotting TR versus puffing time (t) as discussed above.

Table 1 : Values of coefficients of Eq. $TR=Ae^{-K_H t}$ for predicting product temperature during HTST air puffing for complete experimental duration

Temp., °C	Theoretical values			Experimental values		
	A	K_H	R	A	K_H	R
200	0.9435	0.0166	0.9197	0.8355	0.0164	0.9369
210	0.9434	0.0165	0.9185	0.8295	0.0157	0.9332
220	0.9432	0.0164	0.9171	0.8297	0.0150	0.9295
230	0.9428	0.0163	0.9253	0.8401	0.0153	0.9405
240	0.9423	0.0163	0.9262	0.8444	0.0151	0.9434

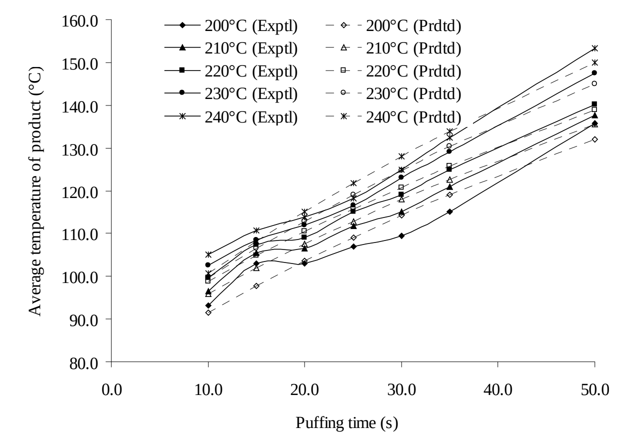

Fig. 1 : Observed and predicted average temperature of snack foods during puffing

The experimental and predicted values of product temperature are plotted against puffing time as shown in Fig. 1.

The theoretical and experimental values of co-efficients of Eq. 4 are as given in Table 1. From Table 1, it could be observed that theoretically calculated and experimentally obtained co-efficients of Eq. 4 were close enough to show that the method and equipment used for measurement of product temperature were appropriate. Though the correlation co-efficients at all the temperatures for both theoretical and experimental co-efficients of Eq. 4 were more than 0.90, during puffing time of 10 to 15 s, the predicted product temperatures were highly deviating from experimentally measured product temperatures. This may be due to the fact that the flat trend of temperature curves during 10 to 15 s of puffing time could be indicating the use of latent heat of vapourization for converting moisture of puffing product into vapours, leading to exerting the pressure within inside the product and making it to get puffed.

Thus, theoretical equations given by Carslaw and Jaegar (1973) and adopted for measuring surface, average and centre temperature of puffing material during hot air puffing are well acceptable.

Conclusion:

The thermo-pack equipment was developed could be reasonably used to measure temperature of rice-soy cold extrudate during hot air puffing. The theoretically calculated and experimentally obtained co-efficients of equation for temperature ratio with puffing time were close enough to show that the method and equipment used for measurement of product temperature during hot air puffing were appropriate. Though the correlation co-efficients at all the temperatures for both theoretical and experimental co-efficients of equation for temperature ratio with puffing time were more than 0.90, during puffing time upto 10 to 15 s, the predicted product temperatures were highly deviating from experimentally measured product temperatures. This may be due to the fact that the flat trend of temperature curves indicating the use of latent heat of vapourization for converting moisture of puffing product into vapours, leading to exerting the pressure within inside the product and making it to get puffed. Thus, theoretical equations for temperature ratio with puffing time adopted for measuring surface, average and centre temperature of puffing material during hot air puffing were well acceptable.

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