Retort process modelling for Indian traditional foods

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Abstract Indian traditional staple and snack food is typically a heterogeneous recipe that incorporates varieties of vegetables, lentils and other ingredients. Modelling the retorting process of multilayer pouch packed Indian food was achieved using lumped-parameter approach. A unified model is proposed to estimate cold point temperature. Initial process conditions, retort temperature and % solid content were the significantly affecting independent variables. A model was developed using combination of vegetable solids and water, which was then validated using four traditional Indian vegetarian products: *Pulav* (steamed rice with vegetables), *Sambar* (south Indian style curry containing mixed vegetables and lentils), *Gajar Halawa* (carrot based sweet product) and *Upama* (wheat based snack product). The predicted and experimental values of temperature profile matched with $\pm 10\%$ error which is a good match considering the food was a multi component system. Thus the model will be useful as a tool to reduce number of trials required to optimize retorting of various Indian traditional vegetarian foods.

Keywords Retort processing · Modelling · Sterilization · Indian traditional foods

Nomenclature

F	Accumulated lethality (min)
f_h	Heating rate constant
j_c	Lag constant
k_c	Empirical model constant for cooling

k_h	Empirical model constant for heating
L	Lethality
t	Time (min)
R^2	Correlation regression coefficient
RMSE	Root mean square error
SS	Sum of squares of errors
T_a	Ambient temperature ($^{\circ}\text{C}$)
T_{cw}	Cooling water temperature ($^{\circ}\text{C}$)
T_p	Product temperature ($^{\circ}\text{C}$) at any time t
T_{p0}	Initial product temperature ($^{\circ}\text{C}$)
T_R	Desired retort temperature ($^{\circ}\text{C}$)
T_{ref}	Reference temperature ($^{\circ}\text{C}$)
z	Slope index of thermal death curve ($^{\circ}\text{C}$)

Greek letters

χ^2 Chi square error

Introduction

Thermal processing is one of the major techniques used for producing packaged shelf-stable food products. Retort processing of foods in semi-rigid, flexible laminates is an advanced form of food preservation by canning. It is a thermal process which imparts increased shelf life with good retention of nutrients and sensory parameters. Although different food processing technologies like high pressure processing, ohmic heating, etc. have been developed for preservation purpose, retort processing and canning are still the most used techniques in the food industry (Chen and Ramaswamy 2002a, b).

Changing lifestyle, increased work pressure and nuclear families are leading to exponential increase in the demand of ready to eat processed food in developing countries like India. A consumer would prefer his traditional food on a daily basis, provided a safe, tasty and

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processed option is available. In spite of old notions and psychological reservations against canned food, Indian market has accepted many retorted and pouch packed products. Traditional Indian vegetarian foods are mostly heterogeneous systems. Typically the recipe incorporates two or more vegetables, lentils, grains and cereals; cooked with spices and condiments. Since fat, spices and protein content of these raw materials is low, one expects the thermal properties to depend only on total solids and water content. Due to cultural diversity, there are over 2,000 different recipes of staple and snack food. As a result, optimized retorting conditions are developed for a specific product. There is a need to have a unified approach of mathematical modelling so that most of the products could be categorized in terms of total solids (plant origin) and water content. Several papers have been reported on product and process development of Indian foods, with most work on non-vegetarian foods such as *Biryani* (Rice with red meat or chicken) and fish curry etc. (Dileep and Sudhakara 2007; Jayakumar et al 2007; Mallick et al. 2006; Ravi Shankar et al. 2002). Non-vegetarian products are of a different class as they contain more proteins and fats, whereas vegetarian products mainly consists of fibres (soluble/insoluble) and starch. Among vegetarian products, rice and curries have been mainly studied. (Abbatemarco and Ramaswamy 1994; Bindu et al. 2007; Chandrasekar et al. 2004; Chandrasekar and Srinivasa Gopal 2008; Geetha and Jayaraj Rao 2008; Prakash et al 2005; Rodríguez et al. 2003). Many of the reports on modelling of vegetarian foods have used Balls model and Stumbo model which has few limitations (Sablani and Shayya 2001). Further, focus of these papers was more on microbial destruction, lethality and heat transfer aspects as very little has been reported on the same. Some recent papers on non-Indian foods report heat transfer studies by using Artificial Neural Network and Genetic Algorithm (Chen and Ramaswamy 2002a, b; 2003; Gonçalves et al. 2005; Sablani and Shayya 2001). Others have used classical modelling as a tool (Alonso et al. 1997; Baucour et al. 2003; Chen and Ramaswamy 2007; Miri et al. 2008; Simpson et al. 2004). These models were however product specific as they were based on thermal properties of that particular product. This work was therefore undertaken with the objective to develop a semi empirical unified model for prediction of time-temperature profile during retorting of Indian vegetarian products. Temperature of the retort vessel, initial product temperature and solid content were the three independent variables considered. Cold point temperature of the retort pouch was estimated as a dependent parameter. The predictive model developed was validated using four different types of traditional Indian foods viz. *Pulav*, a rice product; *Sambar*, a curry product; *Gajar-Halawa*, a sweet product and *Upama*, a snack in a 100 l laboratory retort equipment.

Materials and methods

Retortable pouches (150×200 mm) made with four layers (PET 12/Al 9/NY 15/PP 70 Microns) were procured from Joeltech Inc., Cochin, India. Pouches were filled with 250 g of material prescribed later. A specially designed stainless steel thermo-well was inserted in the pouch so that its tip was in the geometric centre of pouch. It consisted of two rubber O rings, nuts and a space bar having hole in the centre through which a thermocouple could be inserted. A thermocouple (Ellab SSA- 12050-G700-TS stainless steel, Ellab Co. Reodovre, Denmark), capable of measuring temperature in the range of −45 to 135 °C with an accuracy of 0.1 °C and response time of 0.8 s, was placed inside the thermo-well after filling and sealing the pouches. These pouches were then thermally processed in a stainless steel still retort processing unit (Laxmi Engineering, Chennai, India). 36 steam nozzles equally distributed along the walls of retort maintains an even temperature inside the vessel. Residual air in the retort vessel was steam exhausted and pouches were processed at required temperature and pressure. Cold point temperature was monitored in three pouches using a data recorder (Ellab CTF 9008 data recorder, Ellab A/S, Roedvere, Denmark). After processing the pouches at required temperature, they were cooled rapidly by pumping pressurized water into the retort till product temperature reached 50 °C.

Model validation was done by using four traditional Indian vegetarian products: *Pulav* (steamed rice with vegetables), *Sambar* (a south Indian style curry), *Gajar Halawa* (carrot based sweet product), *Upama* (wheat based snack product). Ingredient composition used for method validation for different products were as follows,

Pulav: 260 g Basmati rice, 40 g Green peas, 40 g Carrot, 30 g Corn, 10 g Green chilli, 4 g Clove, 4 g Black pepper, 4 g Salt, 2 g Lemon juice, 42 g Vegetable oil, 564 g externally added water

Sambar: 65 g *Toor dal* (lentils), 46 g Tomato, 90 g Onion, 46 g Drum sticks, 90 g Ash gourd, 46 g Bottle gourd, 11 g Tamarind extract, 8 g Salt, 16 g Spices mix, 5 g Curry leaves, 16 g Groundnut oil, 5 g Mustard, 556 g externally added water

Gajar Halawa: 646 g Carrot, 162 g Sugar, 162 g Mawa (milk solids), 10 g Cardamom, 30 g Cashew nut

Upama: 228 g Sooji (a coarse, sandy fraction of wheat flour obtained in milling), 65 g Onion, 25 g Coriander, 10 g Curry leaves, 25 g Ginger, 12 g Green chilli, 25 g Cashew nuts, 5 g Sugar, 15 g Lemon juice, 25 g Ground nut oil, 5 g Salt, 5 g Mustard, 560 g externally added water

All the ingredients were procured from local market of Mumbai. For *Pulav*, rice, green peas, carrot and corn

Fig. 1 Experimental and Ball's model predicted data for *Sambar* processed in retort

whereas for *Sambar*, *Toor dal* and drum sticks were half cooked for 5 min in boiling water. All the products were processed in the retort processing unit as per the procedure described above. Time-temperature profile was modelled using the proposed model and the constants of the same were used to validate the unified model.

Model development

First step in model development was to test the Ball's model (Eq. 1). Significant literature has reported the use of Ball's model to predict time required for thermal processing of food (Abbatemarco and Ramaswamy 1994; Bindu et al. 2007; Chandrasekar et al. 2004; Chandrasekar and Srinivasa Gopal 2008; Dileep and Sudhakara 2007; Geetha and Jayaraj Rao 2008; Jayakumar et al. 2007; Mallick et al. 2006; Prakash et al. 2005; Ravi Shankar et al. 2002; Rodriguez et al. 2003). Ball's model is as follow,

$$\log(T_a - T_P) = -\frac{t}{f_h} + \log[j_c(T_a - T_i)] \quad (1)$$

Table 1 Ball's model coefficients for different materials in retort pouch

Material in pouch	J_c	f_h
Water	0.88	7.41
Water + Potato Powder	1.29	6.38
Water + Carrot powder	1.13	6.31
Water + Beet powder	1.39	6.34
Water + Spinach powder	1.23	6.22
Water + Tomato powder	1.28	6.25
Water + Bottle gourd powder	1.38	6.26

Where, T_a is ambient (retort) temperature, T_P is product temperature ($^{\circ}\text{C}$), t is time (min), f_h is heating rate constant, j_c is lag constant, T_i is initial product temperature ($^{\circ}\text{C}$). Rearranging Eq. 1 to give product temperature,

$$T_P = T_R - e^{-\frac{2.303t}{f_h} + \ln[j_c(T_R - T_i)]} \quad (2)$$

Correction for cum up time (t_{cut}) may be applied (Paul Singh and Heldman 2004) as,

$$t = t_P + 0.42 t_{cut} \quad (3)$$

The Ball's model was applied to the retort pouches containing different products like *Pulav*, *Sambar*, *Gajar Halwa* and *Upama*. As a sample, results for *Sambar* are presented in Fig. 1. From Fig. 1, it can be seen that even though it gives sufficiently accurate prediction for total thermal processing time, it fails to give continuous time-temperature profile. The Ball's model primarily applies to a cold body immersed in hot environment i.e. it was assumed that environment is at high temperature at time $t=0$. But retort starts getting heated at $t=0$. Although correction for cum up time (Eq. 3) was applied, it was useful only to predict final time required for processing and not for the prediction of entire time-temperature profile and hence later it affected lethality calculation (Eqs. 13, 14), which is function of product temperature.

Since Ball's model did not give satisfactory results, some of the other mathematical correlations were tested to fit the data (Data not reported here). A new semi-empirical model was further proposed to describe time-temperature profile (Eq. 5). The difference between pouch temperature and retort temperature is the driving force for increase in product temperature. Hence ratio of product temperature to retort temperature was considered while developing the model. In differential form, the model is,

$$\frac{dT_P}{dt} = kT_P \left(1 - \frac{T_P}{T_R}\right) \quad (4)$$

Integrating Eq. 4 with initial condition of $T_P = T_{P0}$ at $t=0$ gave,

$$T_P = \frac{T_{P0}e^{kt}}{[1 - (T_{P0}/T_R)(1 - e^{kt})]} \quad (5)$$

Where T_P is product temperature ($^{\circ}\text{C}$) at any time t (min). T_{P0} is initial product temperature ($^{\circ}\text{C}$), T_R is desired retort temperature ($^{\circ}\text{C}$) and k is empirical model constant. For heating and cooling parts, two model constants k_h and k_c were used hereafter. The analysis of experimental data for proposed model is given in section **Model development for simulated system** later.

Next objective was to develop a unified mathematical model that could predict time-temperature profile of all vegetarian products processed in retort. Typical traditional Indian foods essentially consist of: vegetables/cereals, water, salt and/or sugar, spices, fats (oil or ghee). To simulate

Table 2 Box Behnken design of experiments for three factors

A	B	C	Design points	Number of runs
±1	±1	0	Factorial points	4
±1	0	±1	Factorial points	4
0	±1	±1	Factorial points	4
0	0	0	Centre points	1×5=5
			Total	17

Table 3 Coded and actual values of independent variables

Coded values	Retort temperature: T_R (°C)	Initial product temperature for k_h (T_{p0}) or cooling water temperature for k_c (T_{wc}) (°C)	Solid content in pouch (%)
−1	115	35	0
0	120	40	15
1	125	45	30

typical food, these ingredients were grouped in four parts: (i) water: externally added or contained by vegetables (ii) dry solids in vegetables and spices (iii) salt and sugar (iv) fats. Out of which only combination of total solids and water was considered at this stage and salt, sugar and fats were neglected. Thus, major part of any Indian vegetarian food was assumed to be consisting of dry vegetable solids and water. To see whether different vegetable solids have same heating rates or different, an experiment was performed wherein 10 g of dry vegetable powder was added to 90 g water and kept in stainless steel tubes in oil bath at 100 °C. Ball's model was applied as environment is at high temperature at time $t=0$. Values of f_h and j_c were estimated using Microsoft® Excel 2007 SOLVER tool. From Table 1, it was seen that if solid content is same, mixture of any vegetable powder and water had similar heating rates. Thus now the simulated system consisted of (i) different combinations of vegetable solids and water (ii) initial product temperature and (iii) retort temperature. From Eq. 5, it was seen that, new proposed model already had terms of initial product temperature and retort temperature. Hence it was tried to relate empirical model constant k with the solid content.

To arrive at the results in less number of experiments, Response Surface Method was used with Box Behnken orthogonal design of experiments. Three factor- three level Box Behnken design (Box and Behnken 1960) involved total 17 experiments (12 factorial points plus 5 centre points

Table 4 The Box Behnken design matrix of independent variables with their corresponding response

Run	T_R (°C)	T_{p0} (°C)	S (%)	Heating model					Cooling model				
				k_h	SS	RMSE	χ^2	R^2	k_c	SS	RMSE	χ^2	R^2
1	120	45	0	0.456	273.41	2.84	8.29	0.989	0.137	45.84	1.55	2.70	0.996
2	120	45	30	0.425	148.11	1.72	3.02	0.991	0.083	195.58	2.55	6.98	0.989
3	120	40	15	0.330	283.92	1.86	3.51	0.995	0.039	139.24	2.05	4.49	0.991
4	120	35	0	0.528	55.23	1.29	1.73	0.998	0.269	96.40	2.25	5.67	0.992
5	120	40	15	0.309	356.09	2.02	4.14	0.994	0.030	137.78	2.04	4.44	0.991
6	115	35	15	0.361	88.45	1.12	1.26	0.997	0.139	60.04	1.24	1.62	0.996
7	125	35	15	0.331	34.93	0.99	1.00	0.999	0.289	275.04	4.15	19.65	0.972
8	120	35	30	0.222	556.07	3.15	11.50	0.973	0.070	217.27	2.69	7.76	0.986
9	120	40	15	0.384	129.46	1.98	4.05	0.992	0.220	109.47	2.54	7.30	0.988
10	120	40	15	0.337	544.47	3.56	12.96	0.976	0.118	257.84	3.89	17.19	0.974
11	125	45	15	0.347	168.37	2.16	4.81	0.989	0.111	378.63	4.86	27.05	0.956
12	125	40	30	0.335	142.56	1.67	2.85	0.994	0.147	190.63	3.17	11.21	0.983
13	120	40	15	0.302	129.46	1.98	4.05	0.992	0.079	109.47	2.54	7.30	0.988
14	125	40	0	0.541	423.18	2.97	9.00	0.991	0.399	323.15	4.36	21.54	0.967
15	115	45	15	0.295	217.99	1.49	2.25	0.997	0.061	355.16	3.02	9.60	0.981
16	115	40	30	0.421	285.37	2.34	5.60	0.981	0.235	145.08	2.84	9.07	0.977
17	115	40	0	0.571	181.56	2.42	6.05	0.992	0.360	166.85	3.23	11.92	0.979

T_R Retort Temperature (°C), T_{p0} Initial product temperature (°C), S Solid content (%) k_c empirical model constant for cooling, k_h empirical model constant for heating, SS Sum of squares, $RMSE$ Root mean square error, χ^2 Chi square error, R^2 correlation regression coefficient

Fig. 2 k_h as a function of solid content of product in a pouch

to eliminate experimental errors). The design of experiments in coded form is shown in Table 2. Decoded values for the independent parameters are given in Table 3. Retort temperature was varied from 115 °C to 125 °C; initial product temperature was varied from 35 °C to 45 °C whereas solid content in the pouch was varied from 0 % to 30 %. For cooling model, initial product temperature was replaced with cooling water temperature. Experiments were performed in random order and new proposed time-temperature profile model was fitted to each retort run. Statistical parameters such as sum of squares of errors (Eq. 6), root mean square error (Eq. 7), chi-square (Eq. 8) and correlation regression coefficient (Eq. 9) were used to assess the accuracy of models.

$$SS = \sum_{i=1}^N (k_i - k'_i)^2 \quad (6)$$

$$\chi^2 = \frac{\sum_{i=1}^N (k_i - k')^2}{N - z} \quad (7)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (k_i - k'_i)^2 \right]^{1/2} \quad (8)$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (k' - k)^2}{\sum_{i=1}^n (k - k_{av})^2} \quad (9)$$

where k , k' and k_{av} are experimental, predicted and average values of model constant k , SS is sum of squares of errors, RSME is root mean square error, N is number of data points, z is number of constants in the model tested, R^2 is correlation regression coefficient. Modelling was carried out using the least square method and CoStat version 6.4 (CoHort Software, USA) was used to perform this task.

Model constants, k_h and k_c were treated as response to the Box-Behnken design and quadratic model was fitted to relate k_h , k_c and independent process parameters i.e. retort temperature, initial product temperature and solid content in the pouch for k_h whereas retort temperature, cooling water temperature and solid content in pouch for k_c . Design expert (Version 8.0) software was used for analysis of RSM data. Second order polynomial (SOP) model was used to fit the data.

$$Y = \beta_0 + \sum_{i=1}^k \beta_i X_i + \sum_{i=1}^k \beta_{ii} X_i^2 + \sum_{i=1}^k \sum_{j=i+1}^k \beta_{ij} X_i X_j \quad (10)$$

Where, Y is the predicted transform of dependent variable; β_0 is a constant; β_i , β_{ii} and β_{ij} are linear, squared and cross-product coefficients respectively, k is number of factors. Tools provided by the Design Expert were used to calculate model constants and coefficients. Analysis of Variance (ANOVA) was performed for the experimental and predicted responses by these models. Contour and Response surface plots were obtained for the data. Finally the data were also checked for microbial lethality as indicated by predicted F value.

Results and discussion

The present work was undertaken with the objective of developing mathematical expression for time-temperature profile of a retort pouch, developing a unified model and its application to the traditional Indian vegetarian food. The Lump parameter approach with simulated system was used for model development.

Table 5 Model fitting summary

Source	Heating model				Cooling model			
	Sum of squares	Degrees of freedom	F value	p -value	Sum of squares	Degrees of freedom	F value	p -value
Linear	0.019	3	3.54	0.0451	0.014	3	2.63	0.0939
2FI	0.004	3	0.62	0.6151	0.003	3	0.43	0.7372
Quadratic	0.018	3	20.01	0.0008	0.015	3	7.59	0.0133
Cubic	0.002	3	3.79	0.1156	0.003	3	2.59	0.1902

Table 6 ANNOVA table

Source	Heating model			Cooling model		
	Sum of squares	F value	p-value	Sum of squares	F value	p-value
T_R	—	—	—	0.001	0.89	0.3768
T_{P0}/T_{cw}	—	—	—	0.002	3.60	0.0996
S	0.019	76.10	< 0.0001	0.011	15.93	0.0053
T_R^2	0.001	4.39	0.0601	0.007	10.47	0.0143
T_{P0}^2/T_{cw}^2	0.001	4.36	0.0607	0.003	3.92	0.0884
S^2	0.016	63.16	< 0.0001	0.006	8.55	0.0222
$T_R T_{P0}/T_R T_{cw}$	—	—	—	0.001	1.17	0.3161
$T_R S$	—	—	—	0.001	1.49	0.2615
$T_{P0} S/T_{cw} S$	0.003	14.23	0.0031	0.001	1.17	0.3160
Residual	0.003	—	—	0.005	—	—
Lack of fit	0.002	2.31	0.2187	0.003	2.59	0.1902
Pure error	0.001	—	—	0.002	—	—

T_R Retort Temperature (°C), T_{P0}
Initial product temperature (°C),
 S Solid content (%)

Fig. 3 k_h & k_c as a function of independent parameters for the simulated system: (a) k_h as a function of initial product temperature and retort temperature (b) k_h as a function of solid content and initial

product temperature (c) k_c as a function of solid content and retort temperature (d) k_c as a function of solid content and initial product temperature

Fig. 4 Parity plots (a) model predicted vs. experimental k_h for simulated system (b) model predicted vs. experimental k_c for simulated system (c) model predicted vs. experimental values of product temperature for simulated system

Model development for simulated system

In the view of simulated system described in section [Model development](#), the independent process parameters were retort temperature (115–125 °C), initial product temperature (35–45 °C) and solid content (0–30 %). Experimental design was based on Table 2 and experiments were conducted randomly. Each experiment was a separate retort run and the data of the runs was checked if it fitted the newly proposed model (separately for heating and cooling section). It can be seen from Table 4 that new proposed model gave good fit to all the experimental runs. New proposed model gave prediction in 95 % confidence level and $R^2 > 0.97$ for all the runs. To see effect of solid content on heating rate constant, a graph of k_h

vs. solid content was plotted (Fig. 2). But it was seen that all the points were not coinciding for solid content of 0, 15 and 30 % which infers that the other two parameters i.e. retort temperature and initial product temperature also affects k_h . Hence relationship between k_h and k_c and all independent variables were studied by ANOVA. Model was fitted to determine the significance of all terms (linear, two factor interaction, quadratic and cubic) on k_h and k_c (Table 5). It can be seen that p-value for quadratic model was least for both the responses k_h and k_c hence it was selected.

Table 6 is an ANOVA table showing the significance of the independent variables on each of the response variables. Lack of fit test is a measure of failure of a model to represent data in the experimental domain (Montgomery 1984). Analysis of lack of fit was performed for both the dependent variables. Experimental data fitted well to the response surface models as indicated by sufficiently good regression coefficients ($R^2 = 0.9$). Model terms having p-value near to one were neglected from the model as they inflated the system. From Table 6 it can be seen that solid content was affecting k_h on 99 % level whereas linear terms for T_R and T_{P0} were not significant and hence neglected. Second order terms were significant at more than 90 % level. Interacting terms of $T_R - T_{P0}$ and $T_R - S$ were not significant whereas $T_{P0} - S$ was significant at level more than

Table 7 Independent parameters for validation products

Product	Retort temperature (°C)	Initial product temperature (°C)	% solid content
Pulav	125	45	25.8
Sambar	125	35	18.9
Gajar Halawa	120	35	11.4
Upama	120	36	29.9

95 %. Similarly for k_c linear and second order terms of S were significant at 99 % level whereas linear and second order terms of T_R and T_{cw} were significant at level >90 %. Interacting terms were not much significant. Lack of fit was not significant for both the responses.

Surface response plots were generated for both the responses (Fig. 3). Surface plots for T_R and T_{P0} were saddle shape whereas for solid content it passed through minima. This may be due to the fact that initially when solid content in the pouch was low; heat transfer was due to convection. Increase in solid content decreases heating rate upto a certain extent after which a further increase in solid content results in absence of free water in pouch and there was only moist solid. Hence heat transfer was due to conduction in later case and hence k_h or k_c increases again. The SOP model relating k_h and k_c are,

$$k_h^3 = 0.038 - 0.048 S + 0.03 T_{P0} S + 0.016 T_R^2 - 0.016 T_{P0}^2 + 0.061 S^2 \quad (11)$$

$$k_c^2 = 18.91 - 0.36 T_R + 0.14 T_{cw} + 0.01 S - 5.57 \times 10^{-4} T_R T_{cw} - 2.1 \times 10^{-4} T_R S + 1.86 \times 10^{-4} T_{cw} S + 1.63 \times 10^{-3} T_R^2 - 9.95 \times 10^{-4} T_{cw}^2 + 1.63 \times 10^{-4} S^2 \quad (12)$$

Figure 4 shows parity plots for k_h , k_c and overall parity plot showing product temperature prediction which shows that model is giving good prediction of time-temperature profile.

Model validation using traditional Indian foods

In the view of above sections, if retort temperature, initial product temperature and solid content of any product are known, temperature profile followed by the product may be predicted using the unified model developed. If a product has moisture content ≥ 95 , prediction is very easy since the food system will behave similar to water. The main deviation in product properties will be seen when the solid content is 15 % or more. Preliminary investigations on RTE recipes revealed that most of the prepared vegetarian food has maximum solid content of 30 %. Hence for validation of the model four traditional Indian foods, namely *Pulav*, *Sambar*, *Gajar Halawa* and *Upama* were selected. Further, these products also had incorporation of multiple vegetables and in various proportions. Table 7 shows operating conditions of retort and initial conditions of products. Figure 5 shows the plots of predicted and observed values of the cold point temperature over the time for the four products. It may be observed that there was a high correlation between the experimental values and the predicted ones over the whole process. Thus the new proposed model had overcome the disadvantage of the Ball's model. The new

Fig. 5 Experimental and predicted temperature profiles for (a) *Pulav* (b) *Sambar* (c) *Gajar Halawa* (d) *Upama*: (white triangle) Retort temperature (white diamond) Product temperature-experimental (dash) Product temperature-predicted

Table 8 Predicted and observed values of k_h , k_c and F_0

Product	k_h			k_c			F_0		
	Experimental	Predicted	Relative error	Experimental	Predicted	Relative error	Experimental	Predicted	Relative error
<i>Pulav</i>	0.22	0.20	9.30	0.009	0.008	7.79	0.95	0.92	3.16
<i>Sambar</i>	0.36	0.39	8.33	0.130	0.145	11.54	1.98	2.15	8.61
<i>Gajar Halawa</i>	0.23	0.21	8.70	0.060	0.068	13.33	2.34	2.25	3.62
<i>Upama</i>	0.27	0.25	7.41	0.030	0.027	10	2.08	2.26	8.67

proposed model satisfactorily predicted the process behaviour in heating region; however prediction of cooling rate constant (k_c) was not up to the mark (relative error < 10 %) (Table 8).

The microorganism lethality (L) which represents the lethal effect of the thermal treatment at any temperature was calculated ($T_{ref}=121.1\text{ }^{\circ}\text{C}$ and 'z' value = $10\text{ }^{\circ}\text{C}$). The lethality expression is given by,

$$L = 10^{\frac{T-T_{ref}}{z}} \quad (13)$$

And the F value was calculated by integrating the lethality L over the time $t=0$ to t_f ,

$$F = \int_0^{t_f} L dt = \int_0^{t_f} 10^{\frac{T-T_{ref}}{z}} dt \quad (14)$$

F_0 value prediction was in 90 % confidence as relative error was less than 10 % for all the products (Table 8). Although there was a small deviation between the experimental and predicted temperature in that stage of the process, there was a pronounced effect on the F values due to its exponential dependence to temperature (Fig. 6).

In the view of the above discussion, the new proposed model has advantages of continuous time-temperature prediction for the product and sufficiently good prediction of the time required for the processing. Considering the small error obtained, the new model developed is suitable to use as a predictive model for food thermal processing. This model can be further fine tuned to reduce the 10 % error occurred by considering the size and shape of the solids, percentage of salt and sugar, percentage of fats, etc.

Fig. 6 Accumulated lethality over the time for (a) *Pulav* (b) *Sambar* (c) *Gajar Halawa* (d) *Upama*: (white diamond) experimental (dash) predicted

Conclusion

The proposed semi-empirical unified model developed could be successfully extrapolated to predict product temperature over a range of process conditions for various products (relative error < 10 %). Validation with four recipes of Indian traditional food (total solids 10 to 30 %) showed a satisfactory match. Retort temperature, initial product temperature and solid content of the product were found to be significantly important parameters affecting the cold point temperature of the retort pouch. This model is simple to use, does not need exact data on thermo-physical properties of the product and hence will be useful to many other vegetarian products to predict time-temperature profile during retort processing.

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