Design aspect of temperature controlled piston extrusion system for formation of *peda*- milk based sweet


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ABSTRACT

A piston extrusion system was designed for formation of *peda* (milk based sweet). The system is comprised of a jacketed cylindrical barrel, piston, cylindrical die, and temperature controlled water circulator. Piston mechanism was used for pressurized extrusion of the *peda* into disc shape using cylindrical die. Rotary type cutting blade was used to cut the formed *peda*'s at the bottom of the die. Developed system was evaluated on the basis of barrel temperature (26, 30 and 34°C), pressure (270, 540, 810 kPa) and die geometry (1:1, 1:1.5, 1:2). Temperature and moisture content of *peda* mix were the critical factors affecting formation of *peda*. Quality of extruded *peda* sweets pieces were judged on the basis of weight, density, geometrical features (diameter and sphericity), deformation and edge sharpness.

Key words: Extrusion, Milk sweet, *Peda*, Piston, Shape formation.

INTRODUCTION

*Peda* is Indian milk based sweet confection characterized by cream colour and cooked flavour. It is generally prepared by mixing *khoya* and sugar in the ratio 3:1 (Aneja et al., 2002). *Khoya* is an intermediate product obtained by concentrating milk to very high total solids above 67%. *Peda* is expected to have good shelf life in comparison with other milk based sweets due to low moisture content, higher amount of sugar and severe heat treatment applied during its preparation (Londhe et al., 2012). The *khoya*-sugar mixture is heated till the mixture turns relatively firm. If desired, nuts and flavouring substances are added. The contents are mixed thoroughly and made into balls of 15 to 20 gram size by rolling between the palms after applying a little ghee to avoid sticking. The balls are flattened to give them disc shape *Peda* is available in many varieties viz., plain, flavoured, brown etc. (Manjunatha et al., 2012). One of the reasons for number of varieties of *peda* is due to difference in manufacturing technique employed, type and quality of base material (milk/*khoya*) used, added colouring and flavouring substances, individual skills, trade practices and consumers preferences (Banjare et al., 2015). The sensory attributes of different *peda* varieties differ significantly which can be attributed to variation in the method of preparation and varying levels of sugar and moisture content (Rasane et al., 2012). *Peda* by virtue of its lower moisture content and higher sugar content is expected to be less susceptible to microbial spoilage. *Peda* has a short life, maximum up to 15 days at refrigerated temperatures (Indiramma et al., 2002). Shelf life of various varieties of *peda* varies; it also varies with storage temperature and with type of packaging material. Several studies have been carried on shelf life extension of *peda* by suitable packaging (Jha et al., 2015; Banjare et al., 2015) through the addition of ingredients, such as, sorbic acid (Ray et al., 1999) antioxidants and preservatives (Yadav and Beniwal, 2009) etc. Novel processing techniques like microwave has been tried to extend shelf life of *peda* (Naresh et al., 2009).

To develop the mechanized method for formation of *peda* into disc shape, it was decided to develop system based on piston extrusion technology. Extrusion is a frequently used forming technology in the food industry, where the food material may be mixed, wetted, melted, cooked and/or cooled, before being forced through a die in order to achieve a given product shape. Extrusion can be used to generate textures which are otherwise inaccessible (e.g. expanded corn snacks via expansion of a superheated melt), shapes which are otherwise difficult to create while maintaining product quality (e.g. the cold extrusion of chocolate, or characteristics such as surface finish or high density (Rahman et al., 2002). Key mechanical parameters required for equipment design and operation principally involve the response of the material to deformation via extensional and simple shear, while key product quality parameters are related to the microstructure of the final form (Cheyne et al., 2005). High pressure-high temperature extrusion process is widely used for production of extruded snacks, whereas, low pressure-low temperature extruders are used for shape moulding of various food products. There are number of products which are moulded using pressure...
systems, few examples are pasta (Zardetto and Rosa, 2009; Roux et al., 1995), chocolates (Chen and Mackley, 2006), noodles, meat analogues (Rao and Thejaswini, 2015) etc. Peda production involves two distinctly different steps. First step includes preparation of khoa, blending of sugar and other ingredients to prepare khoa-peda mix. Second step involves the pressing and moulding of khoa-peda mix to prepare blobs or peda. For mechanized preparation of peda, system based on piston press technology was developed in this research work and effect of different process parameters on peda formation was studied.

MATERIALS AND METHODS

Design aspects of piston press for peda formation: The equations for design of piston extrusion system are as follows (Sumaila and Ibhadode, 2011):

a) Cylinder capacity

\[ V_t = \pi r_i^2 h + \frac{1}{3} \pi r_i^3 b \]  \hspace{1cm} (1)

\[ M_T = \left( \pi r_i^2 h + \frac{1}{3} \pi r_i^3 b \right) \rho \]  \hspace{1cm} (1)

Where,

- \( V_t \) : Volumetric capacity, m³
- \( M_T \) : Mass capacity, kg
- \( r_i \) : Inner radius, m
- \( h \) : Cylinder height, m
- \( b \) : Cone height, m
- \( \rho \) : Density, kg/m³

b) Cylinder wall thickness

\[ t_c = r_i \left\{ \delta_i \left[ \frac{1}{\delta_i - 2p} \right]^{1/2} - 1 \right\} \]  \hspace{1cm} (3)

Where,

- \( t_c \) : Wall thickness, m
- \( p \) : Internal pressure, N/m²
- \( \delta_i \) : Tangential stress, N/m²
- \( r_i \) : Inner radius of cylinder, m

c) Thickness of conical die geometry

\[ t_d = \kappa D \left( \frac{P}{\delta_i} \right)^{1/2} \]  \hspace{1cm} (4)

Where,

- \( D \) : Diameter of die plate, m
- \( \kappa \) : Coefficient depending upon material of plate
- \( P \) : Internal pressure, N/m²
- \( \delta_i \) : Allowable design stress of cover plate material, N/m²

d) Maximum wall thickness, \( t \)

\[ t = r_i \left\{ \left[ \frac{\delta_i}{\delta_i - 2p} \right]^{1/2} - 1 \right\} \]  \hspace{1cm} (5)

\( t \) : Wall thickness, m

\( p \) : Internal pressure, N/m

\( \delta_i \) : Tangential stress, N/m²

\( r_i \) : Inner radius of cylinder, m

e) Cylinder end-cover plate thickness, \( T \)

\[ t = K D \left( \frac{P}{\delta_i} \right)^{1/2} \]  \hspace{1cm} (6)

\( D \) : Diameter of end cover plate (m)

\( K \) : Coefficient depending upon material of plate

\( P \) : Internal pressure \( \left( \frac{N}{m^2} \right) \)

\( \delta_i \) : Allowable design stress of cover plate material N/m²

f) Bolt design

\[ \frac{\pi D_i^2}{4} P = \left( \frac{\pi D_e^2}{4} \right) \delta_{w'} \]  \hspace{1cm} (7)

\( P \) : Internal pressure (N/m²)

\( D_i \) : Internal diameter of cylinder (m)

\( D_e \) : core diameter of the bolt (m)

\( \delta_{w'} \) : Permissible tensile strength of the bolt

g) Circumferential pitch \( D_p \) of the bolt

\[ D_p = D_i + 2t + 3D_e \]  \hspace{1cm} (8)

\( t \) : thickness of cylinder wall (m)

h) Cylinder Flange

\[ F = \left( \frac{\pi}{4} \right) D_i^2 P \]  \hspace{1cm} (9)

\( D_i \) : Outside diameter of seal (m)

i) Flange thickness determination

\[ t_f = \frac{6M}{b \delta_f} \]  \hspace{1cm} (10)

\( b \) : Width of flange (m)

\( \delta_f \) : Shear stress of flange material \( \left( \frac{N}{m^2} \right) \)

\( M \) : Resultant bending moment (Nm)

Experimental setup: Experimental set up consisted of a cylindrical barrel, conical die, piston, temperature controlled water circulator (Fig. 1). System consisted of upper double
jacketed cylindrical vessel along with three different conical die of different die geometry (Fig. 2). The bore of the barrel may be uniform in diameter from inlet to discharge or it can be tapered, decreasing in diameter from inlet to discharge. Another configuration is represented by a uniform diameter barrel with a final segment tapered or decreasing in diameter. In our design the barrel was of uniform diameter and tapered die geometry was attached at the end of the barrel. SS 304 sheet of 2 mm thickness was used for the formation of cylindrical and conical part of the system. Length of the cylindrical barrel was calculated as 323 mm. Inner and outer diameter of the barrel was 140 and 180 mm respectively. Three different dies were designed having different taperness calculated in terms of die geometry viz., 1:1, 1:1.5 and 1:2. Die was attached to barrel using flange end type connection. Diameter of cylindrical piston was 136 mm and length 50 mm. Rotary type cutting blade was used to cut the formed peda’s at the bottom of the die.

The shape and size of the extruded food product are mainly dependent on the die geometry and the cutting system at the die exit. Die shape and design also influences the finished product geometry and texture. The speed of rotating knife assembly regulates the length of the final extrudate (Maskan and Altan, 2011). Taper die holes create the extrudate with a smooth surface, whereas, a die having abrupt cross sectional changes and short length causes greater mechanical damage to food ingredients and leads to a finer structure and softer texture (Harper, 1989). Large variety products of different shapes can be manufactured using various types of die.

Die geometry ratio was calculated as a/b, where a and b are the horizontal and vertical distance between the bottom edge and the top edge of the cone respectively. Top cylindrical barrel (Fig. 3) and bottom conical die (Fig. 4) were flanged and assembled using nuts and bolts. Three dies were designed with different cone angle, taperness and die geometry (Table 1).
Table 1: Cone angle, taper and die geometry of the conical sections

<table>
<thead>
<tr>
<th>Conical Die No.</th>
<th>Cone angle</th>
<th>Taper</th>
<th>Die Geometry (a / b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90°</td>
<td>200%</td>
<td>1:10</td>
</tr>
<tr>
<td>2</td>
<td>67.38°</td>
<td>133.33%</td>
<td>1:1.5</td>
</tr>
<tr>
<td>3</td>
<td>53.13°</td>
<td>100%</td>
<td>1:20</td>
</tr>
</tbody>
</table>

Performance evaluation: Peda was prepared as per flow diagram given in (Fig. 3). Peda mix was filled in the barrel and was pressed by applying dead weight on the piston. Temperature of peda mass during extrusion was controlled by circulating hot water through the jacketed barrel. Preliminary trials were conducted on the prototype to decide the levels of various process parameters. For each trial 4 kg peda mass was used. Three process variables were temperature (26, 30, 34°C), pressure (270, 540, 810 kPa) and die geometry (1:1, 1:1.5, 1:2). Calculations for die geometry ratio are shown in (Table 2). Peda pieces were visually inspected for deformation and edge sharpness. Response Surface Methodology (RSM) was applied using Design Expert software (version 8.0.0). Central composite rotatable design was used to determine the effect of each factor (variable parameters) on the responses.

RESULTS AND DISCUSSION

Factors affecting peda formation: During preliminary trials it was observed that for preparation of compact and firm peda, moisture content is one of the critical factors. While the extrusion quality of peda depended on machine parameters like temperature and applied pressure. It was observed that barrel temperature and moisture content of peda mix were the important factors affecting pressure requirement for extrusion. The machine parameters affected the extent of deformation and edge sharpness in peda (Table 3). Peda with firm and sharp edges was desirable.

Moisture content of peda mix was kept in the range of 18.45 to 20.19%. At optimum moisture content formed peda is smooth, firm and free from cracks. Also the pressure required for the extrusion is low (270 kPa). The percentage moisture of peda mix fed to the peda forming machine is a critical factor. The surface effects are so pronounced that the success or failure of peda formation depends on the
Table 2: Process variables

<table>
<thead>
<tr>
<th>Factors</th>
<th>Units</th>
<th>Low level</th>
<th>High level</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – Temperature</td>
<td>°C</td>
<td>26</td>
<td>34</td>
<td>26, 30, 34 °C</td>
</tr>
<tr>
<td>B – Pressure</td>
<td>Kg/cm²</td>
<td>0.276</td>
<td>0.828</td>
<td>270, 540, 810 kPa</td>
</tr>
<tr>
<td>C – Die geometry</td>
<td>-</td>
<td>1.0</td>
<td>2.0</td>
<td>1:1, 1:1.5, 1:2</td>
</tr>
</tbody>
</table>

Table 3: Effect of variable parameters on deformation and edge sharpness.

<table>
<thead>
<tr>
<th>Run</th>
<th>Factor 1 A: Temperature °C</th>
<th>Factor 2 B: Pressure kPa</th>
<th>Factor 3 C: Die geometry</th>
<th>Deformation</th>
<th>Edge sharpness*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>30</td>
<td>540</td>
<td>2.0</td>
<td>No</td>
<td>+++</td>
</tr>
<tr>
<td>2.</td>
<td>30</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>+</td>
</tr>
<tr>
<td>3.</td>
<td>34</td>
<td>270</td>
<td>2.0</td>
<td>Yes</td>
<td>++</td>
</tr>
<tr>
<td>4.</td>
<td>30</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>5.</td>
<td>30</td>
<td>540</td>
<td>1.0</td>
<td>Yes</td>
<td>+</td>
</tr>
<tr>
<td>6.</td>
<td>34</td>
<td>270</td>
<td>1.0</td>
<td>Yes</td>
<td>+</td>
</tr>
<tr>
<td>7.</td>
<td>26</td>
<td>810</td>
<td>1.0</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>8.</td>
<td>30</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>9.</td>
<td>34</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>10.</td>
<td>30</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>11.</td>
<td>26</td>
<td>540</td>
<td>1.5</td>
<td>Yes</td>
<td>+</td>
</tr>
<tr>
<td>12.</td>
<td>26</td>
<td>270</td>
<td>1.0</td>
<td>Yes</td>
<td>+</td>
</tr>
<tr>
<td>13.</td>
<td>34</td>
<td>810</td>
<td>1.0</td>
<td>Yes</td>
<td>++</td>
</tr>
<tr>
<td>14.</td>
<td>30</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>+</td>
</tr>
<tr>
<td>15.</td>
<td>34</td>
<td>810</td>
<td>2.0</td>
<td>No</td>
<td>++++</td>
</tr>
<tr>
<td>16.</td>
<td>26</td>
<td>270</td>
<td>2.0</td>
<td>No</td>
<td>+</td>
</tr>
<tr>
<td>17.</td>
<td>30</td>
<td>810</td>
<td>1.5</td>
<td>No</td>
<td>+++</td>
</tr>
<tr>
<td>18.</td>
<td>30</td>
<td>540</td>
<td>1.5</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>19.</td>
<td>26</td>
<td>810</td>
<td>2.0</td>
<td>No</td>
<td>++</td>
</tr>
<tr>
<td>20.</td>
<td>30</td>
<td>270</td>
<td>1.5</td>
<td>Yes</td>
<td>+</td>
</tr>
</tbody>
</table>

* Curved and deformed edge : +
  Sharpen and prominent edge : ++++

moisture content of the material. In a similar dough extrusion study, it was observed that low moisture levels required the highest extrusion pressure, mechanical energy and specific mechanical energy. The consistency coefficient and flow index calculated after dough extrusion in the capillary rheometer were strongly affected by changes in the hydration level of only ±2% and by the formulation of the dough (Peña, 2014). Optimal moisture content of the food material is required at all process stages during extrusion. Changes in one or more variables must be compensated in many cases by different settings of other variables, e.g. a change in the extruder type could be compensated by a certain adaptation of the moisture content (Schmidt and Kleinebuddeb, 1998). For peda mix having less than 19% moisture content higher temperature (>34°C) or pressure (> 810 kPa) was needed for extrusion of peda pieces. Because of low moisture content, peda pieces were hard and dry.

It was observed that by increasing the temperature of the peda mass, pressure for peda formation can be reduced. In the peda formation machine, barrel temperature was maintained by circulating hot water. Optimum temperature for peda formation was in the range of 26-34°C therefore these temperatures were selected for equipment performance evaluation. In this temperature range peda mix was non sticky and extrusion was easy because of slippage phenomena due to the lack of interaction between the cylinder wall and the material itself. It is important to analyse this phenomenon, since the hypothesis of constant tangential stress at the wall and pressure gradient along the cylinder, except in the input section, is valid, in fact, only by imposing the condition of perfect adherence of the test material to the wall. In the presence of slip, this condition is not fulfilled, resulting in unreliable pressure data and viscosity values (Sarghini et al., 2016). Higher temperature resulted in decrease in viscosity of peda mix. At low temperature (< 22°C) peda mass was hard and extrusion of peda was not possible even at higher pressures.

Effect of process variables on various responses

Diameter: The average diameter of peda varied from 44.5 to 58.13 mm. The minimum diameter of 44.5 mm was obtained for the sample which had trial process parameters of temperature: 26°C, pressure: 270 kPa and die geometry ratio: 2.0. While the peda prepared at 34°C temperature, 810 kPa pressure and die geometry 1.0 had maximum diameter of 58.13 mm. Effect of different variables and their interaction effect on the diameter was analysed using RSM.
and are presented in (Fig. 5). Effect of die geometry, temperature and pressure was found non-significant on peda diameter. As shown in (Fig. 5a), considering die geometry at centre point (1.5), with an increase in temperature there was gradual increase in diameter, while increase in pressure resulted in reduction in peda diameter. (Fig 5b) reveals that when the pressure was kept at the centre point 540 kPa, increase in temperature or die geometry resulted in the decrease in diameter. (Fig 5c) shows the effect of die geometry and pressure when temperature was kept at the centre point 30°C. Model is not significant with respect to temperature (P=0.14), pressure (p=0.93) and die geometry (p=0.94). Interaction effect of temperature and pressure (0.71), temperature and die geometry (p=0.82) and pressure and die geometry (p=0.34) is not significant. The prediction equation for the determination of diameter at any given values of process variable is given below.

\[
\text{Diameter (mm)} = 106.38 -1.56T +0.037 P -53.15D -1.80 \times 10^{-3} \times TP +1.58 TD +0.011 PD
\]

Weight: The weight of the peda was significantly (p<0.05) affected by the temperature, pressure and die geometry. It was observed that weight of peda increased with increase in pressure and temperature because of increased flow of peda mix through the die. At the combination of 810 kPa pressure

Fig 5: Effect of process variable on diameter of peda

Fig 6: Effect of process variable on weight of peda
and 34°C processing temperature average weight of peda was 42.5 g. It was seen that the effect of die geometry was more pronounced in comparison to temperature on weight of peda. There was a steep increase in peda weight when die geometry was increased from 1.5 to 2.0. Higher die geometry ratio provided more area before the die outlet. Therefore pressure requirement was lower in case of higher die geometry ratio. The interaction effect of various process variables is shown in (Fig 6). The variations in the weight of peda were due to fixed time interval of cutting system. Weight of peda samples can be altered by changing the time interval for cutting or by varying the machine parameters. The prediction equation for weight of peda on basis of various machine variables is given below.

\[
\text{Weight (g)} = 88.38 - 1.44T + 0.11P - 86.57D + 4.26 \times 10^{-3}TP + 1.95TD - 0.028PD + 0.016T^2 + 5.38 \times 10^{-5}P^2 + 16.20D^2
\]

Density: The average density of peda varied from 1.08 to 1.17 kg/cm\(^2\). The minimum density (1.08 kg/cm\(^2\)) was obtained for the sample, which had trial process parameters of temperature: 34°C, pressure: 810 kPa and die geometry: 2.0. While the peda prepared at trial process parameters of temperature: 30°C, pressure: 810 kPa and die geometry: 1.5 had the maximum density (1.17 kg/cm\(^2\)). Effects of different variables and their interaction effect on the density of peda were analysed using RSM and are presented in (Fig 7). As shown in (Fig 7a), considering die geometry at centre point (1.5), density was almost constant with increase in temperature and with the increase in the pressure the density of peda increased. When the pressure was kept at the centre point 540 kPa density was maximum (1125 kg/m\(^3\)) at 34°C and die geometry ratio of 2 (Fig 7b). Keeping temperature at centre point 30°C, it was observed that pressure had pronounced effect on density as compared to die geometry.

Fig 7: Effect of process variable on density of peda

Fig 8: Effect of process variable on Roundness Ratio
Roundness Ratio: Higher Roundness Ratio (RR) was desirable in peda formation to ensure regular shape of peda. RR of peda was affected by the all the three process variables. It was observed that at 26°C, as pressure was raised from 270 to 810 kPa. RR was maximum (0.98) at 270 kPa and 34°C. At 34°C peda was firm resulting in higher RR values. It was observed that temperature was having more pronounced effect on RR than pressure or die geometry. Effects of different variables and their interaction effect on the roundness ratio of peda were analysed using RSM and are presented in (Fig 8). Higher die geometry ratio resulted in more regular shape of peda. Prediction equation for determining RR is as follows:

$$RR = 0.65 + 7.62 \times 10^{-3} T + 3.58 \times 10^{-5} P + 0.0556D$$

**CONCLUSION**

From this study it was established that piston cylinder system is feasible for peda formation. One of the critical factors for formation of peda was moisture content of peda mix. It was observed that application of pressure resulted in compaction of peda mix. For geometric perfection of formed peda into disc shape, the selected machine parameters were 34°C barrel temperature, 810 kPa extrusion pressure and die geometry ratio 2.

**REFERENCES**


