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ORIGINAL ARTICLE

Performance evaluation of a double drum dryer for potato flake production

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Abstract A double drum dryer working under atmospheric pressure was developed for water evaporation rate of 20 kg/h. Potato slurry of 12% solid concentration was dried to obtain potato flakes. Experiments were carried out at drum speed of 5 to 30 rpm, steam pressure 2 to7 kg/cm^2 gauge (saturation temperature 120–164 °C) and liquid level 5 to 10 cm at the nip of drums. The responses obtained were, moisture content of the potato flakes: 1.18–44.15% (db), dry matter output rate: 1.33–2.87 kg dry solid/h and L value of colour: 30.9–66.4. Steam pressure and drum speed were the most influencing parameters affecting all 3 responses. Optimum combination of operating variables for obtaining potato flakes of 8% (db) moisture content, high dry solid output rate and high L value of colour was: drum speed 19.6 rpm, steam pressure 4.3 kg/cm^2 gauge (saturation temperature 145 °C) and liquid level at the drum nip 6.3 cm. At this combination of independent variables, residence time of the product on drum surface would be 2 s, final moisture content of product 8% (db), product output rate 2.4 kg dry solid/h and L value of colour 53.

Keywords Drum dryer · Potato flakes · Potato slurry · Optimization

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Introduction

Large amount of fresh potatoes are cold stored for use in off-season. Cold-stored potatoes reportedly accumulate reducing sugars, which decline colour quality of processed products (Parkin and Schwobe 1990). Drying of potato after harvesting is one of the ways to overcome the problem of sugar accumulation. Drying of potato slurry produces potato flakes.

Potato flake has wide applications in the making of fabricated potato chips, extruded snacks, snack pellets and battered breaded products. It can be easily reconstituted with cold or hot water and can be used in every household to prepare ready to cook soups, dals, curries, etc. The product has very good demand and wide application in restaurants, fast food chains, catering services and feeding programs. Potato powder is obtained after grinding the potato flakes.

Process of converting potato into flakes involves many stages. At the final stage, potato slurry is dried on a drum dryer. This type of dryer is suitable for products, which are viscous in their natural state or after concentration such as mashed potatoes, precooked starchy baby foods, casein, milk, maltodextrins and fruit pulps (Falagas 1985).

Potato slurry is spread on the surface of heated drum where steam condenses inside the drum. Heat is transferred through the metal of drum and moisture is removed from the slurry adhering the drum. Using a scraper blade dried material is scraped. A screw conveyor is used to convey the scraped material. Short exposure time of the slurry on drum surface reduces the risk of damage to product. As boiling type of drying takes place on the drum surface, dried product becomes very porous, easy to rehydrate and ready to use (Vasseur et al. 1991; Vlachos and Karapantsios 2000).

A double drum dryer having 20 kg/h water evaporation capacity was developed and potato slurry was used as the feed. Drum speed, steam pressure and liquid level at the nip of 2 drums were varied as independent parameters. Measured responses were product moisture content, dry matter output rate and colour of dried product.

The aim of the present study was to determine the optimum operating conditions of the dryer for high production rate of light coloured potato flakes having maximum of 8% moisture content (db).

Materials and methods

Double drum dryer developed at SSP Ltd., Faridabad, comprised of 2 hollow drums so that steam could be introduced into the drums (Fig. 1). The drums were made of stainless steel (AISI304) having length 750 mm, outer diameter 350 mm and thickness 10 mm. Effective area of drum surface available for drying was 1 m^2. Drums were driven with a variable speed drive so that their speed of rotation could be varied between 5 and 30 rpm. A scraper blade was fitted to the drum at an appropriate location such that the residence time of feed on drum surface could vary between 1.33 and 8 s. A 100 l/h capacity rotary type feed pump was used (Fig. 1). A variable speed drive could vary flow rate of the pump.

Potato slurry was prepared and used. It was fed to the dryer and it dried as the drum rotated towards the scraper blade, which scraped out thin layer of dry material from the drum surface. After removal from the drum, a screw conveyor could break the film into easy-to-handle particles. The screw conveyor had the diameter and pitch of 100 mm.

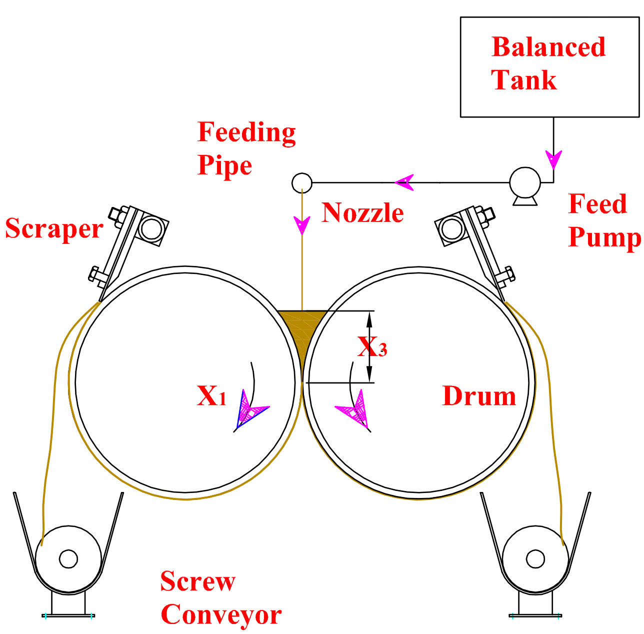


Fig. 1 Different parts of double drum dryer

'Kufri chandramukhi' variety potato was used for the preparation of slurry, because of its higher flour recovery (90.1% db) as compared to other varieties available in market (Marwaha and Sandhu 2001).

Fifty kg of freshly harvested potatoes were procured from market and washed with clean water to remove dirt and other undesirable materials. Sound and uniform sized potatoes of diameter 70–100 mm were sorted. Mechanically damaged, rotted and discoloured potatoes were removed. Sorted potatoes were peeled manually using a potato peeler. Discoloured potato with black spots and potatoes with insect injuries were removed. The eyes and all bruises were pitted out. Peeled potatoes were cut into 20–30 mm size and dipped in water containing potassium metabisulphate (1,000 ppm) for 20 min. The potatoes were softened by blanching them in 50 l of water at 90 °C for 30 min. A mixer operated by a single-phase 1 hp motor was used to smash the blanched potatoes and convert them into slurry. The slurry was filled inside an 80 mesh size bag and pressure was applied by using a screw press. As the filtered slurry coming out of the bag was very viscous, water was added in steps to reduce its viscosity. An indication of total soluble solid concentration of the slurry was obtained by measuring its refractive index. At 10.5° Brix refractive index, total solid concentration of the slurry, as measured by oven drying method, was 12% (wb). In all the experiments Brix reading of slurry was fixed at 10.5° by adding required amount of water to the filtered potato slurry.

The gap between the drums was fixed at 0.5 mm by using a feeler gauge. Drums were rotated and steam was supplied to heat the drums. For some time in the beginning water was used as the feed to stabilize the operating conditions of dryer. Although water was found leaking through the gap of 0.5 mm, this was not so in the case of potato slurry. Speed of the feed pump was increased so that the slurry could flow through the nozzles (Fig. 1) and get collected at the nip of the 2 drums. Liquid level at the nip could be adjusted by controlling the speed of the feed pump. The liquid pool started to boil. After 2–3 min the dry product was scraped out and collected in trays for about 1 min. Changing the drum speed and the liquid level in the pool were carried out at about 4–5 min interval. Dry samples were cooled to room temperature (25–30 °C), sealed inside flexible pouches and taken for moisture and colour measurements. Dried product was ground and colour readings were taken by using a Konica Minolta CR-400 (Japan) colorimeter. Since light colour potato flakes are preferred, only L value of the colour was used in the analysis. Moisture content (% wb) of the ground potato flakes was determined by using Shimadzu (Model MOC-120H, Japan) moisture meter.

Drum speed, steam pressure and liquid level at the nip of the 2 drums were varied as independent parameters. Measured responses were product moisture content, dry matter output rate and the colour of dried product. Experiments were carried with 3 independent variables, viz., drum speed (X_1), steam pressure (X_2) and liquid level at the nip of the two drums (X_3). Effect of feed concentration on production of pregelatinized starch in a double drum dryer was studied by Kalogianni et al. (2002). This variable was not considered. Rotatable central composite design (RCCD) with 3 variables at 5 levels for each of the variables was adopted (Das 2005). Data on moisture content (wb) of the product, amount of product scraped out by the knife in 1 min and L value of product colour were obtained. From the values of wet basis moisture content W and product output rate m (g/min), dry basis moisture content, M_C, (kg water/kg dry solid) and dry matter output rate O_R (kg dry solid/h) were calculated by using Eqs. (1) and (2), respectively.

$$M_C = \frac{W}{100 - W} \times 100 \tag{1}$$

$$O_R = \frac{m}{1000}(60)\frac{(100 - W)}{100} \tag{2}$$

On the basis of information available through published literature and the personal experience of the authors, maximum X_{max} and minimum X_{min} values for X_1, X_2 and X_3 were fixed. These values are X_{1max}=30 rpm, X_{1min}= 5 rpm, X_{2max}=7 kg/cm^2 gauge, X_{2min}=2 kg/cm^2 gauge, X_{3max}=10 cm and X_{3min}=5 cm.

Twenty experiments were carried out following the RCCD (Das 2005). This type of experimental design requires that the experiments be carried out at 5 levels for each of the variables. When the X_{max} and X_{min} values are coded with +1.682 and −1.682, respectively, the 5 values of independent variables in their coded form should be +1.682, +1, 0, −1, −1.682. Real values of 3 independent variables at 5 levels and their corresponding coded values are given in Table 1. Column 1–4 of Table 2 shows the experimental design.

Experimental values of M_C (kg water/kg dry solid) and dry matter output rate O_R (kg dry solid/h) and L value of colour were fitted to second order regression equation in terms of real X and coded x values of independent variables. Coefficients of X and x, X^2 and x^2, X_1X_2 and x_1x_2, X_2X_3 and x_2x_3 & X_2X_3 and x_2x_3 of the regression equations were found out using Design expert software (Version 7.1.1, Statease Inc., Minneapolis, USA).

Relative deviation percentage R_d between the experimental Y_a and predicted Y_p values of dependent variables (which are M_C, O_R and L), as obtained from the Design expert software, was calculated from the following equation.

$$R_d = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{Y_a - Y_p}{Y_a}\right| \tag{3}$$

where, n is the number of experiments carried out.

Results and discussion

Effect of drum speed, steam pressure and liquid level between the drums on the dry basis moisture content, dry solids output rate and L value of colour of potato flakes are shown in Table 2. It may be observed from the Table that moisture content (% db) varied between 1.2 and 44.2%, dry solids output rate between 1.3 and 2.9 kg dry solids/h and L value of colour between 30.9 and 66.4.

Effect of process variables on product moisture content - Following regression equations between the moisture content M_C (% db) of potato flakes and the independent variables were obtained by using the Design expert software.

$$\begin{aligned} M_C = {} & 6.18 + 4.29x_1 - 9.20x_2 + 0.35x_3 - 2.73x_1x_2 \\ & + 0.63x_1x_3 - 0.29x_2x_3 + 0.36x_1^2 + 5.18x_2^2 \\ & - 0.78x_3^2 \end{aligned} \tag{4}$$

$$\begin{aligned} M_C = {} & 35.32 + 1.04X_1 - 21.99X_2 + 5.14X_3 \\ & - 0.25X_1X_2 + 0.06X_1X_3 - 0.13X_2X_3 \\ & + 0.0065X_1^2 + 2.34X_2^2 - 0.35X_3^2 \end{aligned} \tag{5}$$

Table 1 Coded and actual values of independent variables

Independent variables	Symbol	Coded values				
		−1.682 Actual values	−1	0	+1	+1.682
Drum speed, rpm	X_1	5	10	17.5	25	30
Steam pressure, kg/cm^2	X_2	2	3	4.5	6	7
Liquid level, cm	X_3	5	6	7.5	9	10

Table 2 Experimental values of moisture content, dry solid output rate and colour of potato flakes

Expt No.	Drum speed, X_1 rpm	Steam pressure X_2 kg/cm^2 gauge	Liquid level at nip, X_3 cm	Product moisture content, W % wb	Product output rate, m g/min	Hunter colour, L	Product moisture content, M_C % db	Dry solids output rate, O_R kg dry solid/h
1	24.9	6.0	9.0	4.5	42.3	60.1	4.7	2.4
2	24.9	6.0	6.0	4.2	40.4	50.6	4.4	2.3
3	24.9	3.0	9.0	20.2	54.6	30.9	25.2	2.6
4	24.9	3.0	6.0	17.7	52.2	47.8	21.5	2.6
5	10.1	6.0	9.0	1.4	32.3	49.8	1.5	1.9
6	10.1	6.0	6.0	1.3	30.3	65.1	1.3	1.8
7	10.1	3.0	9.0	8.0	37.2	66.4	8.7	2.1
8	10.1	3.0	6.0	8.9	36.2	46.9	9.8	2.0
9	30.0	4.5	7.5	13.9	55.6	36.4	16.2	2.9
10	5.0	4.5	7.5	1.9	22.6	52.7	1.9	1.3
11	17.5	7.0	7.5	1.2	30.4	43.9	1.2	1.8
12	17.5	2.0	7.5	30.6	55.6	58.6	44.2	2.3
13	17.5	4.5	10.0	5.9	43.2	54.4	6.3	2.4
14	17.5	4.5	5.0	5.1	39.1	38.9	5.3	2.2
15	17.5	4.5	7.5	5.6	41.0	40.2	6.0	2.3
16	17.5	4.5	7.5	6.0	41.4	33.2	6.4	2.3
17	17.5	4.5	7.5	5.6	42.2	56.5	5.9	2.4
18	17.5	4.5	7.5	6.0	41.1	36.7	6.4	2.3
19	17.5	4.5	7.5	5.4	42.9	52.2	5.8	2.4
20	17.5	4.5	7.5	5.8	42.3	46.0	6.1	2.4

where, x_1, x_2 and x_3 are the dimensionless coded values of drum speed X_1 (rpm), steam pressure X_2 (kg/cm^2 gauge) and liquid level at the nip of the two drums X_3 (cm) respectively. Values of x and X are related by the following equations, which are applicable to all the regression equations that are presented later.

$$x_1 = 0.08X_1 - 1.4 \tag{6}$$

$$X_1 = 12.5x_1 + 17.5 \tag{7}$$

$$x_2 = 0.4X_1 - 1.8 \tag{8}$$

$$X_2 = 2.5x_2 + 4.5 \tag{9}$$

$$x_3 = 0.4X_3 - 3 \tag{10}$$

$$X_3 = 2.5x_3 + 7.5 \tag{11}$$

Equations (6) to (11) have been developed by using the following data X_{1max}=30, X_{1min}=5, X_{2max}=7, X_{2min}=2, X_{3max}=10, X_{3min}=5, such that the maximum and minimum values of the coded variable x lie between +1 and −1 respectively (Das 2005).

Predicted values of M_C, as obtained by Eqs. (4) or (5) when compared with the experimental values given in Table 2, relative deviation percentage R_d (Eq. 3) of 18.5 is obtained.

Following observations can be made from Eq. (4) and the analysis of variance, as obtained from the Design expert software.

1. Coefficient of x_2 is negative, but that of x_1 and x_3 are positive; therefore increase in steam pressure will reduce the moisture content M_C whereas, increase in drum speed and liquid level at the nip of the drums will increase the moisture content.

   Above findings, as obtained from mathematical analysis, are due to the following phenomena that takes place on drum dryer.

   i) Higher steam pressure increases drum surface temperature, increases moisture removal rate from feed and thereby reduces the product moisture content.
   ii) Higher drum speed reduces residence time of feed on drum surface and thereby increases the product moisture content.
   iii) Higher liquid level at the nip of the two drums creates higher pressure for the liquid entrainment on the drum surface. This produces greater flow of

feed to drum surface, resulting higher moisture content in the dried product.

From the experiments carried out on single and double drum dryers, similar observations were made by Daud and Armstrong (1987), Fritze (1973), Rosenthal and Sgarbieri (1992), Trystram (1988), Vasseur et al. (1991), Trystram and Vasseur (1992), and Vallous et al. (2002).

2. Coefficient of x_2 is highest i.e. 9.2 and this is followed by the coefficient 4.29 of x_1 and the coefficient 0.35 of x_3. Therefore, the effect of steam pressure on product moisture content is highest; this is followed by drum speed and liquid level at the nip of 2 drums.
3. From the analysis of variance it was found that the effect of drum speed, steam pressure and liquid level at the nip of 2 drums on product moisture content were highly significant ($p \leq 0.01$). In Eq. (4), x_1, x_2, x_1x_2 and x_2^2 are significant ($p<0.05$) model terms. For these terms computed values of p are 0.0027, 0.0001, 0.0376 and 0.0006 respectively. Thus the ANOVA reveals that drum speed and steam pressure are the major parameters responsible for moisture content of potato flakes.

Using Eq. (5), a surface plot was made (Fig. 2) to show the variation of product moisture content M_C at different values of drum speed X_1 and steam pressure X_2 at a constant value of depth X_3 (since this variable has the least effect on M_C) of liquid at the nip of two drums. In Fig. 2 the value of X_3 was kept at the mid value (7.5 cm) of the maximum (10 cm) and minimum (5 cm) values of X_3. Fig. 2 shows that the effect of X_2 on M_C is more non-linear than the effect of X_1 on M_C. This can also be verified from Eq. (4) where, we find the coefficient of x_2^2 (5.18) is higher than the coefficient of x_1^2 (0.36).

Effect of process variables on dry product output rate - Following regression equations could be developed between dry matter output rate O_R (kg dry solids/h) of potato flakes and the independent variables.

$$O_R = +2.36 + 0.35x_1 - 0.12x_2 + 0.049x_3 - 0.016x_1x_2 - 0.0068x_1x_3 + 0.013x_2x_3 - 0.0814x_1^2 - 0.095x_2^2 + 0.00126x_3^2 \quad (12)$$

$$O_R = +0.365 + 0.11X_1 + 0.286X_2 + 0.009X_3 - 0.0014X_1X_2 - 0.00062X_1X_3 + 0.00588X_2X_3 - 0.00147X_1^2 - 0.043X_2^2 + 0.0057X_3^2 \quad (13)$$

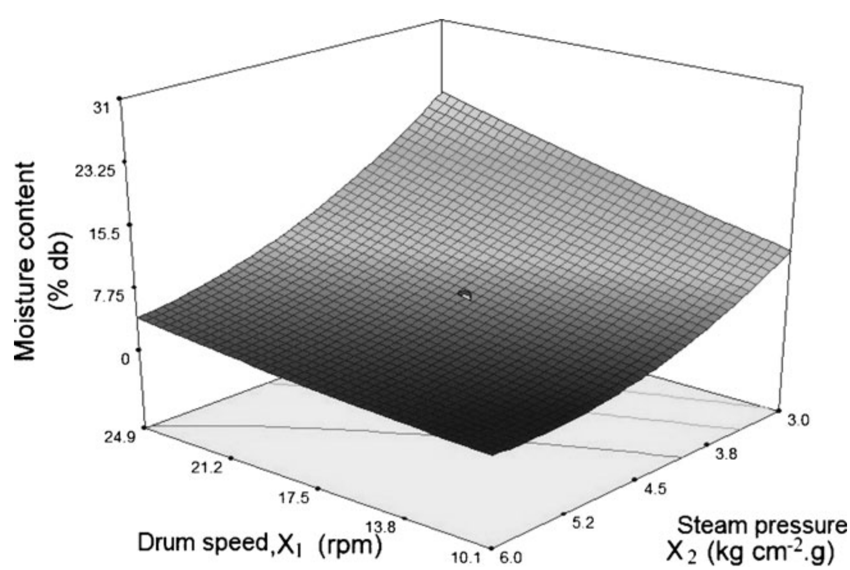
where, x_1, x_2 and x_3 are the dimensionless coded values of drum speed X_1 (rpm), steam pressure X_2 (kg/cm^2 gauge) and liquid level at the nip of two drums X_3 (cm), respectively. Values of x and X are related by the Eqs. (6)–(11).

Predicted values of O_R, as obtained from Eqs. (12) or (13), when compared with the experimental values given in Table 2, the computed value of relative deviation percentage R_d (Eq. 3) was 13.8.

Following observations could be made from Eq. (12) and the analysis of variance, as obtained from the Design expert software.

1. Coefficient of x_2 is negative but that of x_1 and x_3 are positive; therefore increase in steam pressure will reduce the dry solids output rate whereas, increase in

Fig. 2 Effect of drum speed and steam pressure on product moisture content at 7.5 cm depth of liquid at the nip of 2 drums



drum speed and liquid level at the nip of the drums will increase this rate.

Following physical phenomena that take place on drum dryer have lead to the above-mentioned observations.

i) Increased steam pressure increases product temperature at the nip of the two drums. Higher temperature reduces feed viscosity, reduces the entrainment flow of liquid on drum surface and thereby reduces dry solid output rate.
ii) Higher drum speed and higher depth of liquid at the nip of the drums create greater entrainment flow of feed liquid to drum surface and, this results in increasing the dry solid output rate.

This type of effect of independent variables on dry soild output rate is found matching with previous studies carried out by Rosenthal and Sgarbieri (1992) and Vallous et al. (2002) on drying of fresh sweet corn and pregelatinized starch respectively using double drum dryer.

2. Coefficient of x_1 is highest (0.35) and this is followed by the coefficient (0.12) of x_2 and 0.049 of x_3. Therefore, effect of drum speed on dry solids output rate is highest; this is followed by the effect of steam pressure and liquid level at the nip of two drums.
3. From the ANOVA it was found that the effect of drum speed, steam pressure and liquid level at the nip of the drums on dry matter output rate of product were highly significant ($p \le 0.01$). In Eq. (12), x_1, x_2, x_1^2 *and* x_2^2 are the significant model terms. For these terms the p values are 0.0001, 0.0044, 0.0283 and 0.0135, respectively. Thus, the ANOVA reveals that drum speed and steam pressure are the major parameters responsible for dry matter output rate of potato flakes.

Using Eq. (13), a surface plot (Fig. 3) was made. The figure shows the variation of dry solids output rate O_R at different drum speed X_1 and steam pressure X_2 at a constant value of depth X_3 (since the effect of X_3 on O_R is the lowest) of liquid at the nip of two drums. In Fig. 3 the value of X_3 was kept at mid value (7.5 cm) of the maximum (10 cm) and minimum (5 cm) values of X_3.

It can be seen from Fig 3 that steam pressure is having negative slope while drum speed is having positive slope. Also, the effect of steam pressure X_2 and drum speed X_1 on dry product output rate is non-linear. The degree of the two non-linearity is close to each other; as we find from Eq. (12), coefficients of x_2^2 is 0.095, and the coefficient of x_1^2 is 0.081.

Effect of process variables on colour of potato flakes Following regression equations between the L value for colour of potato flakes and the independent variables were obtained by using the Design expert software.

$$L = +50.00 + 1.70x_1 - 11.15x_2 - 0.12x_3 - 1.11x_1x_2 - 1.55x_1x_3 + 1.45x_2x_3 - 2.94x_1^2 + 0.014x_2^2 + 0.048x_3^2 \quad (14)$$

$$L = +72.012 + 3.6X_1 - 10.7X_2 - 3.804X_3 - 0.1008X_1X_2 - 0.14063X_1X_3 - 0.655X_2X_3 + 0.0532X_1^2 + 0.00634X_2^2 + 0.216X_3^2 \quad (15)$$

where, x_1, x_2 and x_3 are the dimensionless coded values of drum speed X_1 (rpm), steam pressure X_2 (kg/cm^2 gauge) and liquid level at the nip of the two drums X_3 (cm) respectively. The predicted values of L by Eqs. (14) or (15) when compared with the experimental values given in Table 2, relative deviation percentage R_d (Eq. 3) of 3.5 is obtained.

Following observations can be made from Eq. (14) and the analysis of variance, as obtained from the Design expert software.

1. Coefficient of x_2 and x_3 are negative but that of x_1 is positive. Therefore, higher steam pressure, higher depth of liquid at the nip of 2 drums and lower drum speed will reduce the L value of product. Colour change during drying is the result of complex reactions taking place between food components. In general, increased temperature and residence time increases the colour and reduces L value. The effect of increased steam pressure increases the drum surface temperature and this reduces the L value. Increased depth of liquid at the nip of 2 drums and the reduced drum speed increase the residence time of liquid at the nip of the drums and on drum surface; resulting lowering of L value.
2. Coefficient of x_2 is highest (11.2) and this is followed by coefficients 1.7 of x_1 and 0.12 of x_3. Therefore effect of steam pressure on L value of colour of product is highest which is followed by the effect of drum speed and liquid level at the nip of the drums on L value of colour of product.
3. From the ANOVA it was found that the effect of drum speed, steam pressure and liquid level at the nip of the drums on L value for colour of product were highly significant ($p \le 0.01$). In this case x_2 and x_1^2 are significant ($p \le 0.05$) model terms. For these terms the p value were 0.0001 and 0.0041, respectively. Thus, the ANOVA reveals that steam pressure and drum speed are the major parameters responsible for colour of potato flakes.

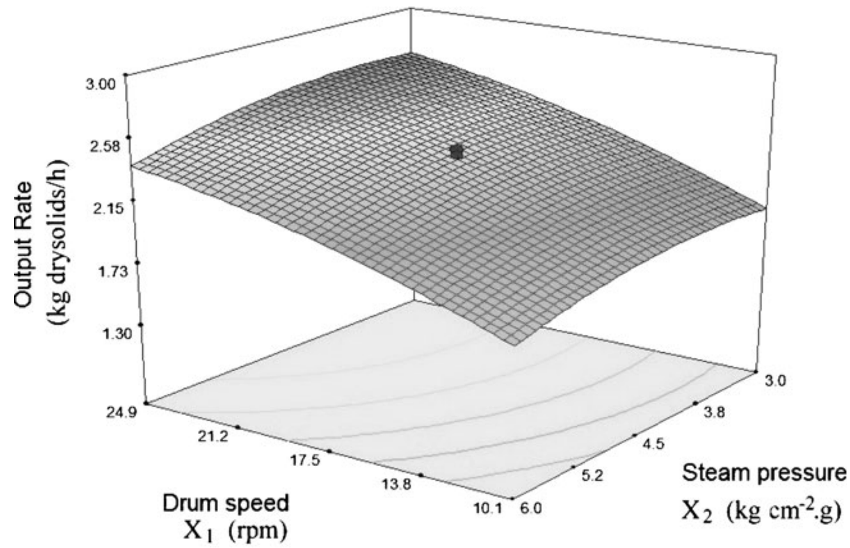


Fig. 3 Effect of drum speed and steam pressure on dry solid output rate at 7.5 cm depth of liquid at the nip of 2 drums

Using Eq. (15), a surface plot (Fig. 4) was made to show the variation of L value at different drum speed X_1 and steam pressure X_2 at a constant value of depth X_3 of liquid at the nip of two drums. In Fig. 4 the value of X_3 was kept at mid value (7.5 cm) of the maximum (10 cm) and minimum (5 cm) values of X_3. Fig. 4 shows that the effect of X_1 on L value is more non-linear than the effect of X_2. This can also be verified from Eq. (14) where we find the coefficient of x_1^2 (2.94) is higher than the coefficient of x_2^2 (0.014).

Optimization of process variables Optimization of process conditions for drum drying of potato flakes was done by using the Design Expert software. Franke et al. (2008) have shown that potato flakes should have a maximum of 8% (db) moisture content for high storage stability. Accordingly, one of the objective functions for optimization was that the value of M_C should be lower than 8 kg water/kg dry solid. From economic point of view the dryer should have high dry solid output rate O_R. The dried potato flakes should be of light colour, therefore the value of L should be high. Under these criteria, optimum operating conditions of the drum dryer for production of potato flakes, as found out from the Design expert software, were drum speed: 19.6 rpm, steam pressure: 4.3 kg/cm^2 gauge (steam temperature of 145 °C) and liquid level at the drum nip of two drums 6.3 cm. The responses predicted by design expert for these combinations independent parameters are final moisture content of product: 8% (db) output rate of potato flakes: 2.43 kg dry solids/h and L value of colour: 53.

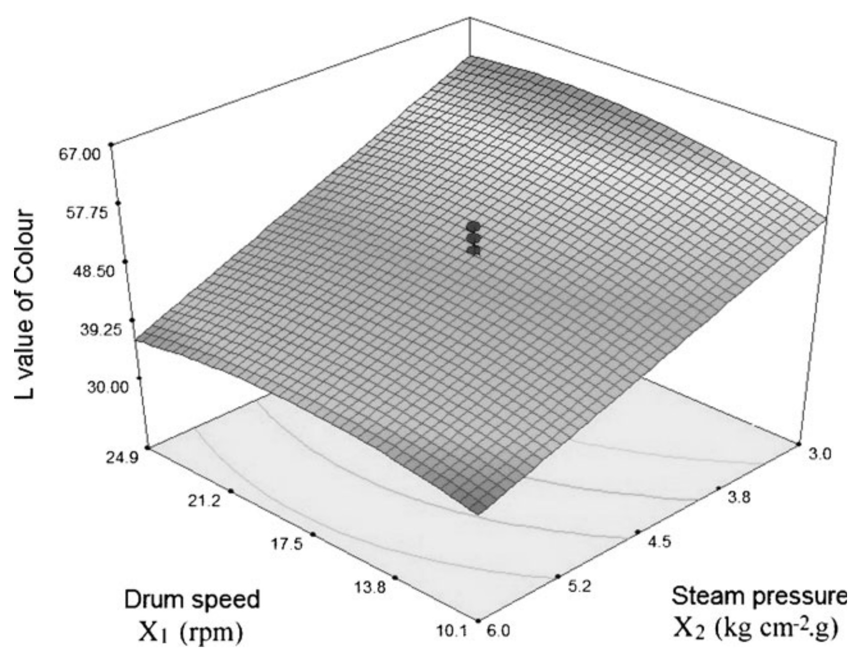


Fig. 4 Effect of drum speed and steam pressure on L value for colour of product at 7.5 cm depth of liquid at the nip of 2 drums

Conclusion

Drum drying is used for products, which are not so heat sensitive. The present paper describes the optimization of twin-drum drying parameters for production of potato flakes. Investigations were carried out to find out optimum values of drum speed, steam pressure and liquid level at the nip of two drums, such that the dried product would be light colored flakes having safe moisture content and high dry solid output rate. Empirical models developed would be able to predict the values of responses at different values of the independent parameters.

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