Chapter 43
Minimizing Solid Not Fat Loss in Whey During Paneer Manufacturing Using Taguchi Orthogonal Array

Sudip Banerjee, N. M. Suri, Sumankant, Subrata Kumar Bag, and Sandeep Kumar Khatkar

Abstract Paneer, a popular Indian dairy product, is obtained by acid coagulation of milk. Among several parameters that affect this process; the heating temperature of milk (A), coagulation temperature (B), the strength of coagulant (C) and immersion time in chilled water (D)are the most important. These factors affect the process of paneer production heavily and thus the correct combination of these four factors will minimize the loss incurred during processing. Here, L_{27} Taguchi Orthogonal array design was adopted with 4 factors and 03 levels to determine the conditions for the process to yield optimum result. Smaller the loss of Solid not fat (SNF) in whey, better was the combination of parameters. After each trial, paneer whey was tested for its final composition. It was perceived that the best result was realized using the combination of labelled as $A_3B_3C_2D_2$. The SNF content in whey, in this case, was minimum and was recorded as 5.5%. For validation, a confirmation test was conducted with the proposed combination of parameters and it was concluded that this combination is good enough to achieve the lowest SNF loss in whey or to maintain maximum milk solids in paneer.

Keywords Whey · Paneer · Fat · Solid not fat · Optimization · Taguchi · Waste reduction

S. Banerjee (✉) · N. M. Suri · Sumankant
Department of Production & Industrial Engineering, Punjab Engineering College, Chandigarh, India

S. K. Bag
Deapartment of Dairy Engineering, West Bengal University of Animal & Fishery Sciences, West Bengal, Kolkata, India

S. K. Khatkar
Department of Mechanical Engineering, Chandigarh Engineering College, Landran, Punjab, India

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43.1 Introduction

As per statistics from the year 2014–2019, it was recorded that the paneer marketplace in India nurtured with a CAGR of 12.5%. Paneer is a non-fermentative, non-renneted and non-melting type of cheese, attained by acid and heat coagulation of milk [1]. It is deliberated as one of the most widely consumed dairy product in India [2]. While producing paneer, cheese or chhana significant quantity of whey is produced. Whey constitutes about 45–50% of total milk solids, 70% of the milk sugar (lactose), 20% of the milk proteins and 70–90% of the milk minerals and almost all the water-soluble vitamins originally present in milk [3]. Whey when prepared during paneer manufacturing with the help of coagulant such as citric acid, a significant quantum of solid not fat removed from the paneer and incorporated in whey. Citrate content in paneer whey was higher due to the addition of citric acid as a coagulant during the preparation of paneer. The outcomes are in agreement with the observations reported by several scientists about the composition of paneer and cheese whey [4]. Khan and Pal [1] reported that the strength of coagulant has a significant consequence on the final body and texture of paneer. Rajashekhar et al. [5] observed that citric acid paneer produces softer body in comparison to other coagulants.

SNF % in whey is influenced by the entire paneer manufacturing process which requires many process parameters with a low, medium and high level of interactions resulting in the variance in final production. The Standard operating parameters traditionally designed are not based on optimization, taking into consideration of all majorly interacted process parameters. Hence the final output in terms of SNF in whey is required to be optimized (minimization of SNF in whey in this case). Several experimentations have to be conducted for a complete experiment [6–8]. To overcome this problem, the Taguchi method applies a special design of orthogonal arrays to examine the whole parameter space with only a small number of trials [9–11]. For the manufacturing of paneer four factors are measured as controlling factors. These are heating temperature, coagulation temperature, the strength of coagulant and immersion time of paneer blocks in chilled water.

For the Literature review, it has seen that consideration of multiple factors together such as heating temperature, coagulation temperature, the strength of coagulant, immersion time etc. have not experimented altogether [12,13]. It is fairly fascinating to understand the consequence of all these four factors and their interactions (combined effect) on the SNF content in whey. In addition to that, this investigation is meant to optimize the production factors put on Taguchi's orthogonal array. In convention, the standard operating process (SOP) for paneer manufacturing designed does not base upon any sort of optimization taking into consideration of all majorly interacted process parameters. Hence there is enough scope for the enhancement of the final output result in terms of lowermost SNF content in whey. Regarding the waste minimization, it has been observed that a significant volume of whey is drained during the production of paneer which contains an average 5.9% SNF. Therefore there is ample scope for more reduction of SNF in whey thereby saving the milk solids and ensuring the profitability. Therefore, in this investigation, the effect of various control parameters such as heating temperature, coagulation temperature, the strength of coagulant and immersion time on SNF content in whey have been investigated using Taguchi optimization technique.

43.2 Material and Manufacturing of Paneer

The paneer was produced in Verka Ludhiana Dairy, Ludhiana. For manufacturing paneer, milk was taken at 4–6 °C and standardized to desired fat and SNF % [14]. Therefore, the same was transported through a plate heat exchanger to 85–95 °C for 10 min and impelled into a cheese vat where milk was cooled to 72–80 °C. One of the reasons for high heat treatment was to impart a desirable cooked flavour [15]. Moreover, the heating helped to cook the milk for speedy iso-electric precipitation, regulate the moisture content of paneer, mature distinctive body and consistency [13]. Therefore, hot milk was coagulated at 72–80 °C by adding citric acid at pH 5.3–5.4 with the help of citric acid. Here normally 1.8 kg of citric acid is immersed in 120 kgs of pasteurized hot water to get the desired concentration of 1.5% of citric acid (range 1–2%). The same may be sprinkled over the entire mass for better coagulation process. Higher concentration may impart an acidic flavour in paneer.

Three factors such as type of acid, its concentration and delivery mode and amalgamation into hot milk effect the yield of paneer and moisture withholding [16]. After coagulation, clear greenish-yellow whey splits out letting curd to shrink to the lowermost of the paneer vat. Therefore whey was drained through the filter and the curd mass was transferred to stainless steel grooved hoops kept inside the muslin cloth. The hoops have perforations on all edges to enable escaping out the whey. Four to five paneer hoops holding 7.5–10 kg paneer were placed one above another and pneumatic pressure of 6–10 kg/cm^2 is applied for 10–12 min. Finally cut paneer blocks are immersed in chilled water from 1 to 2 h for the preparation of the final composition of the product. After the immersion, paneer blocks are taken out of chilled water and kept on the SS table with the cover of wet muslin cloth. After that, the blocks are cut into pieces as per requirement, weight and packed below 15 °C. Paneer pieces then kept at the cold store at less than 4 °C for overnight to make it ready for dispatch. The SOP for paneer manufacturing depicted in Figs. 43.1 and 43.2.

43.3 Problem Identification and Design of Experiment

Problem identification stated with brainstorming followed by the voice of the customer (VOC). Then VOC turned to CTQ (Critical to Quality). Next probable reason for SNF loss in whey is grouped through the cause-effect diagram. After that pilot experimentation conducted to identify the manufacturing parameters and their

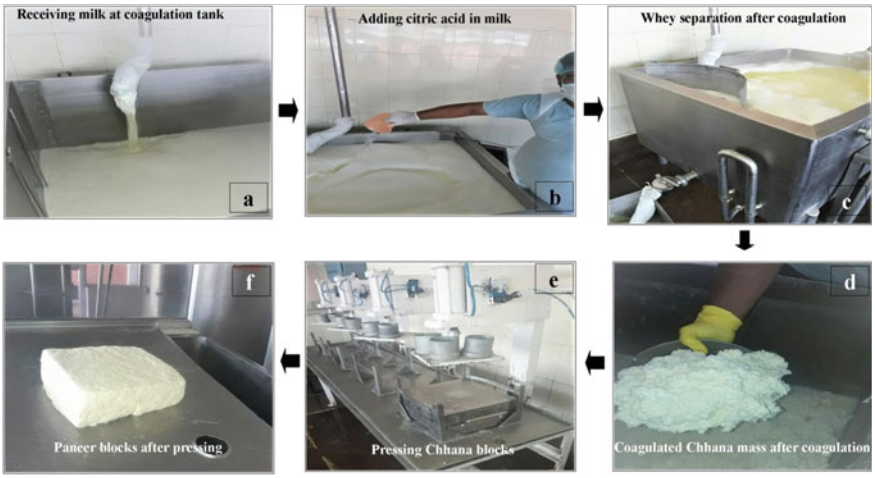

Fig. 43.1 a–f Process layout of manufacturing of paneer

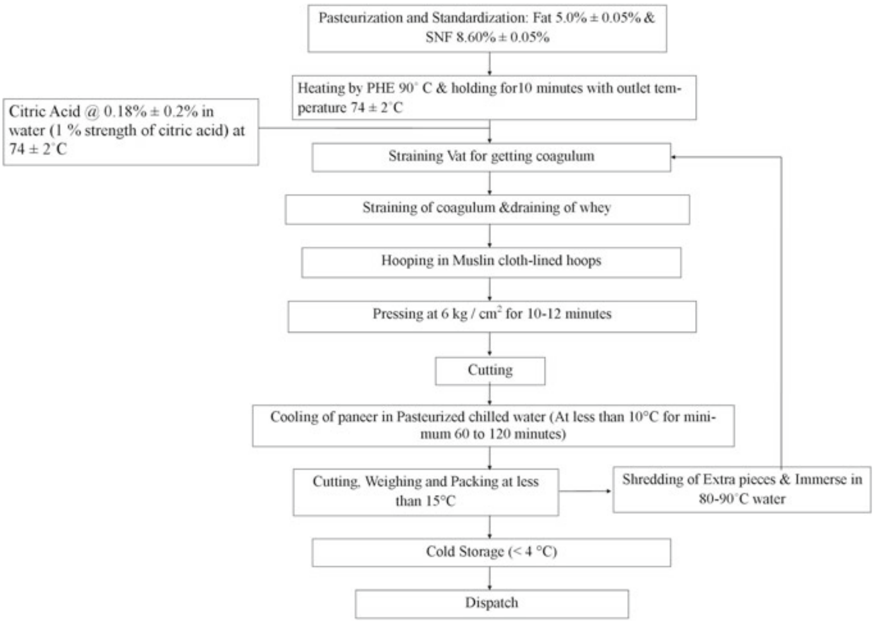

Fig. 43.2 Flow diagram for the manufacture of paneer

Table 43.1 Average SNF % in whey with different parameters at a different level of experiments

	Parameters	L1		L2		L3	
		%SNF in whey	S/N ratio	%SNFin whey	S/N ratio	%SNF in whey	S/N ratio
A	Heating temp. (°C)	5.9	−15.41	5.9	−15.41	**5.8**	−15.38
B	Coagulation temp. (°C)	6.0	−15.63	5.8	−15.41	**5.7**	−15.16
C	Strength of coagulant (%)	5.8	−15.38	**5.8**	−15.31	5.9	−15.51
D	Immersion time (h)	5.9	−15.49	**5.8**	−15.30	5.9	−15.41

*L1, L2 and L3 represent Levels 1,2 and 3 respectively
** S/N Ratio symbolizes Signal to Noise ratio

levels. The process factors for paneer were identified as heating temperature, coagulation temperature, the strength of coagulant and immersion time of paneer blocks in chilled water. Then research design was prepared by L27 Taguchi orthogonal array as shown in Table 43.1. From the paneer manufacturing trial, selected-response characteristic was recorded as SNFcontent in whey. Finally, the effect of all control parameters on response characteristics was studied individually applying Taguchi single response optimization [12]. The same was validated through a confirmation experiment for each factor. In the case of paneer whey "Smaller the better (SB)" concept is applied to minimize the SNF content in whey.

43.4 Result and Discussion

SNF content in whey during the manufacturing of paneer has been considered as a response, however, heating temperature, coagulation temperature, the strength of coagulant and immersion time have been taken as input parameters for the manufacturing of paneer. The raw data for average values of the responses for every factor considered in all three levels (L1, L2 and L3) and depicted in Table 43.1.

After conducting the three experiments for each of the 27 trials i.e. a total of 81 experiments, results were obtained in terms of average SNF% in paneer whey. Experimental results for % SNF in whey are summarized in Table 43.2. From the average values and main effect of the raw data of SNF in whey (Table 43.3), it is noticed that the control parameter coagulation temperature has the strongest influence on SNF % in whey followed by immersion time, the strength of coagulant and heating temperature. The coagulation is a process of curdling through precipitation. That is the settlement of solid not fat. Hence coagulation temperature has significant impact over the solid not fat of milk taken for the manufacturing of paneer.

Tabl 43.2 SNF Content in whey according to different experimentation combination

Trial No	Trial combination				% SNF in whey			Average % SNF in whey	S/N ratio
	A	B	C	D	S1	S2	S3		
1	85	72	1	1	6.70	6.60	6.40	6.57	−16.3485
2	85	72	1.5	1.30	6.00	6.20	6.30	6.17	−15.8028
3	85	72	2	2	6.50	6.40	6.30	6.40	−16.1243
4	85	76	1	1.30	6.00	5.80	5.90	5.90	−15.4179
5	85	76	1.5	2	5.80	5.60	5.40	5.60	−14.9675
6	85	76	2	1	6.00	6.00	6.00	6.00	−15.5630
7	85	80	1	2	5.40	5.30	5.80	5.50	−14.8139
8	85	80	1.5	1	5.40	5.30	5.80	5.50	−14.8139
9	85	80	2	1.30	5.40	5.30	5.80	5.50	−14.8139
10	90	72	1	1	6.20	6.30	6.00	6.17	−15.8028
11	90	72	1.5	1.30	5.80	5.90	6.00	5.90	−15.4179
12	90	72	2	2	6.00	6.30	6.10	6.13	−15.7557
13	90	76	1	1.30	6.00	5.80	6.00	5.93	−15.4671
14	90	76	1.5	2	6.00	6.00	5.90	5.97	−15.5149
15	90	76	2	1	6.00	5.80	5.90	5.90	−15.4179
16	90	80	1	2	5.80	5.60	5.40	5.60	−14.9675
17	90	80	1.5	1	6.00	6.00	6.00	6.00	−15.5630
18	90	80	2	1.30	5.40	5.30	5.80	5.50	−14.8139
19	95	72	1	1	5.40	5.30	5.80	5.50	−14.8139
20	95	72	1.5	1.30	5.40	5.30	5.80	5.50	−14.8139
21	95	72	2	2	6.20	6.30	6.00	6.17	−15.8028
22	95	76	1	1.30	5.80	5.90	6.00	5.90	−15.4179
23	95	76	1.5	2	5.80	5.90	5.90	5.87	−15.3681
24	95	76	2	1	6.00	6.00	6.00	6.00	−15.5630
25	95	80	1	2	5.90	5.90	5.80	5.87	−15.3681
26	95	80	1.5	1	6.00	6.00	6.00	6.00	−15.5630
27	95	80	2	1.30	6.00	6.20	6.10	6.10	−15.7074

*A, B, C and D denote Heating Temperature (*OC*), Coagulation Temperature(*OC*), the strength of coagulant(%) and Immersion Time respectively

For computing S/N ratio for smaller is better, the following formula is used:
Smaller is better: S/N_{LB} ratio $= -10 \log (1/r \sum yi^2)$,
Where yi = individual response.

Table 43.3 Percent contribution and optimum factors

Designation	Parameter	Optimum level	Optimum value	Mean of SW(% C)	S/N ratio of SW(%C*)
A	Heating temp (°C)	3	95 °C	0.16	0.12
B	Coagulation temp (°C)	3	80 °C	21.84	21.49
C	Strength of coagulant (%)	2	1.5%	3.75	3.69
D	Immersion time (h)	2	1.30 h	3.88	3.76

*% C denotes % contribution

The main effect and S/N ratios for SNF % in whey are stated in Figs. 43.2 and 43.3 respectively. The mean response denotes to the average measure of quality characteristics for every factor at altered levels. The average value of SNF % in whey for every factor at levels 1, 2, and 3 are computed. In Fig. 43.3a, it was observed that with an increase in temperature (i.e. 80, 85 and 90 °C) the SNF content was decreased. Also as shown in Fig. 43.3b with an increase in coagulation temp. the SNF content decreased significantly. In Fig. 43.3c SNF quantity decrease for raising coagulation strength from 1 to 1.5%. SNF further increases due to the increase in strength of coagulant from 1.5 to 2%. In case of increase of immersion time from 1 to 1.30 h, SNF in whey decreases and increase in immersion time from 1.30 to 2 h, SNF in whey increase.

Table 43.3 shows that the contribution of parameter i.e. coagulation temperature, to the responses is greatest (21.84%). The influence of other factors in downward

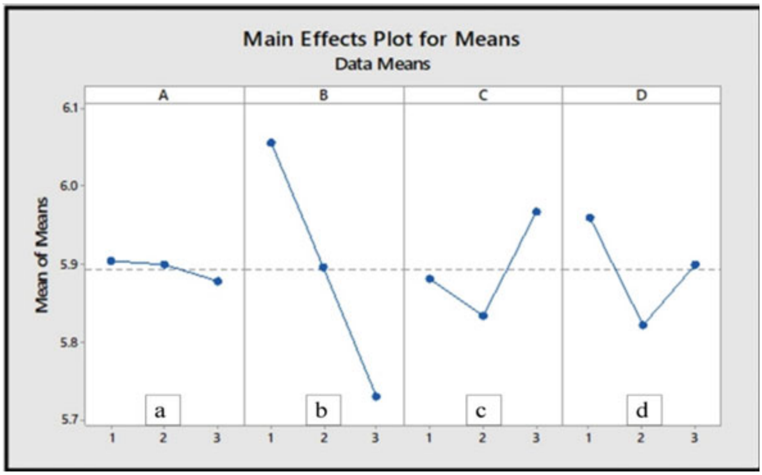

Fig. 43.3 Main effects graph with the mean for SNF% in whey

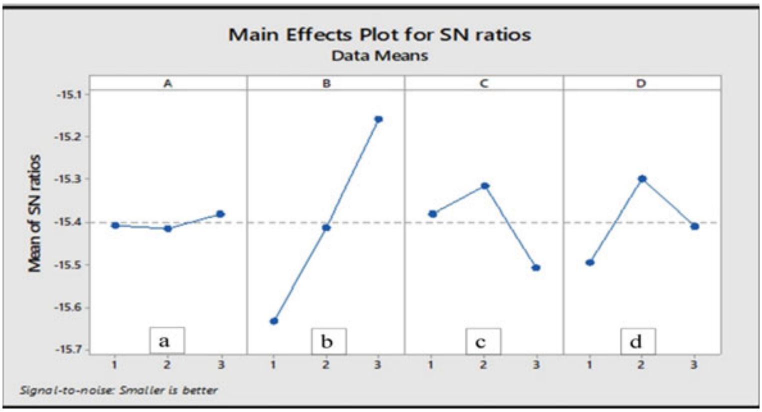

Fig. 43.4 Main effects graph with the S/N ratio for SNF% in whey

order is immersion time (3.88%), % coagulant used (3.75%), and heating temperature (0.16%). Thus, depending on the main effect, S/N ratio and ANOVA analysis, the optimal mixture of factors and their levels for attaining lowest SNF % in whey is $A_3B_3C_2D_2$ i.e. the Heating temperature at level 3 (95 °C), coagulation temperature at level 3 (80 °C), % Coagulant used at Level 2 (1.5%), and immersion time at level 2 (1.30 h).

As SNF % in whey is smaller is better type, the lower value of SNF % in whey is preferred. From Figs. 43.3 and 43.4, it is projected that the combination $A_3B_3C_2D_2$ provides the minimum value of SNF % in whey. Moreover, in almost all the factors A, B, C and D, the lowest value of mean response relate to the highest value of S/N ratio. It was observed that The optimal value of the predicted mean (μ) of different response characteristics can be available from the below-stated equation also adopted by [7, 8].

$$\mu = m + \left(m_{Aopt} - m\right) + \left(m_{Bopt} - m\right) + \left(m_{Copt} - m\right) + \left(m_{Dopt} - m\right)$$

$$\mathrm{m} = \frac{T}{N}$$

where,

m	overall mean, average SNF % in whey = 5.89
T	a total of average SNF% in whey for each experiment = 477.4
N	total number of experiments = 81
m_{Aopt}	average SNF % in whey for factor A at its optimal level = 5.8
m_{Bopt}	average SNF % in whey for factor B at its optimal level = 5.7
m_{Copt}	average SNF % in whey for factor C at its optimal level = 5.8
m_{Dopt}	average SNF % in whey for factor D at its optimal level = 5.8

While Calculating we get the mean for selected trial conditions for parameters at ($A_3B_3C_2D_2$) is 0.72 (m)

$$\begin{aligned}\mu &= 5.89 + (5.8 - 5.89) + (5.7 - 5.89) + (5.8 - 5.89) + (05.8 - 5.89)\\ &= 5.89 - 0.09 - 0.19 - 0.09 - 0.0-\\ &= 5.43.\end{aligned}$$

43.4.1 The Confidence Interval Around the Estimated Mean

The optimum value of SNF % in whey is projected at the designated levels of factors. The production factors and their optimum levels have already been designated as $A_3B_3C_2D_2$ shown in Table 43.3.

There are three different types of confidence intervals (CIs) that Taguchi practices, depending on the purpose of the estimation [17]. The 95% confidence interval of confirmation experiments (CI_{CE}) and the population (CI_{POP}) is evaluated by applying the subsequent equations[10]:

$$CI_{CE} = \left[F(\alpha, 1, v_e)V_e\left({}^1/_{\eta_{eff}} + \frac{1}{r}\right)\right]^{1/2}$$

$$CI_{POP} = \left[F(\alpha, 1, v_e)V_e\left({}^1/_{\eta_{eff}}\right)\right]^{1/2}$$

where,

α = the level of risk;

ν_e = the degrees of freedom for the error;

F((α, 1, v_e)= The F ratio at the confidence level of (1- α) against DOF 1 and error DOF ν_e;

V_e = the error variance,

η_{eff} = the effective number of replications and r is the number of test trials.

r = Sample size for confirmation experiments;

η_{eff} = effective number of replications = (N/(1 + DOF));

Using the above values, the CI is calculated as given under

$$\eta_{eff} = N/(1 + Total\ degree\ of\ freedom\ associated\ in\ the\ estimate\ of\ mean)$$

= 81/(1 + 8) = 9.

α = 1–confidence limits (95%) = 0:05.

$F_{ratio(1;0:05;6)}$ = 5.99.

Table 43.4 Result of the confirmation run

Experiment with $A_3B_3C_3D_3$	SNF % in whey
1	5.50
2	5.45
3	5.55
Average	5.50

43.4.2 Confirmation Experiments

Confirmations experiments are performed to endorse that the parameters and levels were designated from an experiment cause a product or technique to turn in a specific mode. If the average of the outcomes of the confirmation experiment is outside the range of the Confidence Interval, the factors voted and/or levels to regulate the fallouts for the anticipated value are indecorous or have extreme measurements, necessitatingextrainvestigation. Here $A_3B_3C_2D_2$ did not associate to any trial of the orthogonal array. A total of three (3) confirmation experiments was carried out in the same way as discussed (Table 43.4) and average SNF % in whey was computed.

The average of the respondent SNF % in whey in every trial is found to be 5.50%, which is within the CI I.e$5.29 < 5.50 < 5.569$ of the predicted value of the SNF in whey. This suggests that nominated factors, as well as their suitable levels, are appropriate to attain the anticipated outcome.

43.5 Conclusion

In the current static investigation, the process parameters (such as heating temperature, coagulation temp., the strength of coagulant and immersion time) of fabrication of paneer with low SNF was optimized using the Taguchi approach. From the experimental investigation the following main conclusions can be drawn:

1. The optimal paneer manufacturing conditions for getting lower most SNF percentage in whey are Heating Temperature as 95 °C (level 3), coagulation temperature as 80 °C (level 3), the strength of coagulant as 1.5% (level 2) and Immersion Time as 1.30 h (level 2).
2. The percentage contribution of the parameter coagulation temperature on SNF content of paneer is highest (21.84%) followed by immersion time (3.88%), the strength of coagulant (3.75%) and heating temp. (0.6%).
3. Before the use of the Taguchi orthogonal array, the SNF content in whey was 5.90%, whereas, after the use of Taguchi's method, the SNF content in whey drastically reduced to 5.50% only, resulting in maximum SNF retention in paneer.

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