International Journal of Mining Science and Technology 23 (2013) 717–724

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Application of response surface methodology and central composite rotatable design for modeling the influence of some operating variables of the lab scale thickener performance

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ARTICLE INFO

Article history:
Received 15 December 2012
Received in revised form 20 January 2013
Accepted 28 February 2013
Available online 3 September 2013

Keywords:
Response surface methodology
Central composite rotatable design
Modeling
Thickener

ABSTRACT

This study discussed the application of response surface methodology (RSM) and central composite rotatable design (CCRD) for modeling and optimization of the influence of some operating variables on the performance of a lab scale thickener for dewatering of tailing in the flotation circuit. Four thickener operating variables, namely feed flowrate, solid percent, flocculant dosage and feedwell height were changed during the tests based on CCRD. The ranges of values of the thickener variables used in the design were a feed flowrate of 9–21 L/min, solid percent of 8%–20%, flocculant dosage of 1.25–4.25 g/t and feedwell height of 16–26 cm. A total of 30 thickening tests were conducted using lab scale thickener on flotation tailing obtained from the Sarcheshmeh copper mine, Iran. The underflow solid percent and bed height were expressed as functions of four operating parameters of thickener. Predicted values were found to be in good agreement with experimental values (R^2 values of 0.992 and 0.997 for underflow solid percent and bed height, respectively). This study has shown that the RSM and CCRD could efficiently be applied for the modeling of thickener for dewatering of flotation tailing.

1. Introduction

The thickening process is the primary method of producing high solid slurries for the mining industry. Thickener outputs can accommodate a range of tailings disposal options from low yield stress, easily pumped suspensions for disposal in conventional wet tailings dams to more concentrated slurries for delivery to dry disposal and backfill applications. The thickening process, although operated successfully in a large range of sites around the world, is poorly understood and predictive design of thickening devices is still empirical. Although predictive models of thickening do exist, the correlation to reality is often poor, and there is a desperate need to bring the two together to make rational improvements on thickener design and operation. Therefore, whilst some would dismiss the models as being unacceptable for predictive design, they are very useful in formulating expected operational trends and providing an understanding of the directions one should take in improving operational performance [1]. The efficient solid–liquid separation of mineral suspensions in gravity thickeners is of importance to most hydrometallurgical processing operations. The main features of a thickener are represented in Fig. 1. Low solids feed streams are pumped into the feedwell, generally with a high inlet velocity. Initially, thickeners and their feedwells were designed to dissipate the energy of the incoming feed, with the solids then allowed to settle and consolidate in the main body of the thickener. Fine particle slurries have very low settling rates, with thickening then only practical if high molecular weight water-soluble polymers (flocculants) are used to induce aggregation and thereby enhance sedimentation. Flocculant solutions are typically mixed with the feed slurry through addition to the feedwell, although feedpipe addition can be used concurrently or as an alternative [2].

This study also involved modeling and optimization of process parameters affecting the lab scale thickener performance. The general practice for determining the important process parameters is by varying one parameter and keeping the others at a constant level. This is the one-variable at-a-time technique. The major disadvantage of this technique is that it does not include interactive effects among the variables and, eventually, it does not depict the complete effects of various parameters on the concentration process. In order to overcome this problem, optimization studies can be carried out using the response surface methodology (RSM). The basic theoretical and fundamental aspects of RSM have been described in related literature. RSM

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2095-2686/$ - see front matter © 2013 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2013.08.016

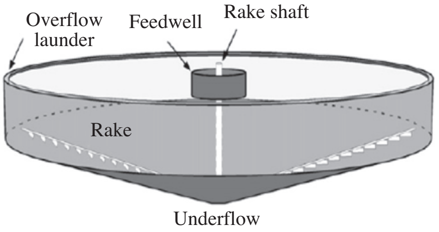

Fig. 1. Main features of a thickener.

Table 1
Relationship between coded and actual values of a variable.

Code	Actual value of variable
$-\beta$	x_{min}
-1	$[(x_{max}+x_{min})/2]-[(x_{max}-x_{min})/2\alpha]$
0	$(x_{max}+x_{min})/2$
+1	$[(x_{max}+x_{min})/2]+[(x_{max}-x_{min})/2\alpha]$
$+\beta$	x_{max}

Note: x_{max} and x_{min} = maximum and minimum values of x, respectively; $\alpha = 2k/4$; k = number of variables.

Table 2
Independent variables and their levels for CCRD.

Variable	Symbol	Coded variable level				
		Lowest	Low	Center	High	Highest
		$-\beta$	-1	0	+1	$+\beta$
Feed flowrate (L/min)	*A*	9.00	12.0	15.00	18.0	21.00
Solid percent (%)	*B*	8.00	11.0	14.00	17.0	20.00
Flocculant dosage (g/t)	*C*	1.25	2.0	2.75	3.5	4.25
Feedwell height (cm)	*D*	16.00	18.5	21.00	23.5	26.00

reduces the number of experimental trials needed to evaluate multiple parameters and their interactions; therefore it is less laborious and time-consuming than other approaches. RSM has been applied for modeling and optimizing in mineral processing [3]. Process parameters selected in this investigation for the thickener's performance are feed flowrate, solid percent, flocculant dosage and height of feedwell.

2. Materials and methods

2.1. Response surface methodology

RSM is a collection of statistical and mathematical methods that is useful for modeling and analyzing engineering process. In this technique, the main objective is to optimize the response surface that is influenced by various process parameters. RSM also quantifies the relationship between the controllable input parameters and the obtained response surfaces. The design procedure of RSM is as follows [4–9]:

(1) Designing of a series of experiments for adequate and reliable measurement of the response of interest.
(2) Developing a mathematical model of the second-order response surface with the best fittings.
(3) Finding the optimal set of experimental parameters that produces maximum or minimum value of response.
(4) Representing the direct and interactive effects of process parameters through 2D and 3D plots.

If all variables are assumed to be measurable, the response surface can be expressed as follows [9–11]:

$$y = f(x_1, x_2, x_3, \ldots, x_k) \tag{1}$$

Table 3
Central composite design consisted of experiments for the study of four experimental factors in coded and actual levels with experimental results.

No.	Test number	Coded level of variable				Actual level of variable				Observed	
		A	*B*	*C*	*D*	Feed flowrate (L/min)	Solid percent (%)	Flocculant dosage (g/t)	Feedwell height (cm)	Underflow solid percent (%)	Bed height (cm)
1	8	+1	+1	+1	+1	18	17	3.50	23.5	40.2	12.0
2	22	+1	+1	+1	−1	18	17	3.50	18.5	38.6	20.5
3	18	+1	+1	−1	+1	18	17	2.00	23.5	35.0	36.5
4	11	+1	+1	−1	−1	18	17	2.00	18.5	31.7	44.0
5	12	+1	−1	+1	+1	18	11	3.50	23.5	30.0	19.0
6	24	+1	−1	+1	−1	18	11	3.50	18.5	29.0	20.0
7	29	+1	−1	−1	+1	18	11	2.00	23.5	22.5	30.0
8	4	+1	−1	−1	−1	18	11	2.00	18.5	25.4	38.5
9	5	−1	+1	+1	+1	12	17	3.50	23.5	35.0	9.0
10	3	−1	+1	+1	−1	12	17	3.50	18.5	33.0	14.0
11	1	−1	+1	−1	+1	12	17	2.00	23.5	29.0	29.0
12	15	−1	+1	−1	−1	12	17	2.00	18.5	29.7	23.5
13	23	−1	−1	+1	+1	12	11	3.50	23.5	23.0	11.5
14	25	−1	−1	+1	−1	12	11	3.50	18.5	25.0	12.5
15	9	−1	−1	−1	+1	12	11	2.00	23.5	20.0	24.5
16	7	−1	−1	−1	−1	12	11	2.00	18.5	22.7	27.0
17	2	0	0	0	0	15	14	2.75	21.0	34.0	21.3
18	13	0	0	0	0	15	14	2.75	21.0	32.8	19.7
19	19	0	0	0	0	15	14	2.75	21.0	33.5	20.0
20	21	0	0	0	0	15	14	2.75	21.0	33.1	20.0
21	27	0	0	0	0	15	14	2.75	21.0	34.0	21.0
22	30	0	0	0	0	15	14	2.75	21.0	33.0	19.5
23	10	+2	0	0	0	21	14	2.75	21.0	31.0	39.0
24	16	−2	0	0	0	9	14	2.75	21.0	23.0	11.0
25	17	0	+2	0	0	15	20	2.75	21.0	42.2	18.5
26	26	0	−2	0	0	15	8	2.75	21.0	20.3	21.5
27	20	0	0	+2	0	15	14	4.25	21.0	32.0	9.5
28	28	0	0	−2	0	15	14	1.25	21.0	28.0	32.0
29	14	0	0	0	+2	15	14	2.75	26.0	31.0	23.5
30	6	0	0	0	−2	15	14	2.75	16.0	30.6	25.0