

Optimization of Flotation Reagents' Specific Consumption by Modeling During Mineral Enrichment

A. Alouani

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Abstract

Introduction-Flotation is a process of separating precious minerals from the gangue, based on the differences in the surface properties of the particles, using reagents added in the presence of air bubbles. The consumption of flotation reagents represents a very important part in the mineral enrichment cost. In this study of optimizing the mineral flotation reagents consumption, we have empirically modeled the concentrate contents according to the influence of elements, based on the experimental designs theory [1][2][3][4]. The purpose of this study is to determine the optimal experimental conditions, in order to study the main effects of the different parameters and the effects of possible interactions between them, which cannot be revealed by conventional methods. The method of factorial design was applied to optimize the specific consumption of flotation reagents [5][6][7].

Index terms—

1 Introduction

II.

2 The Experimental Designtheory

The experimental design methodology is also an effective experimental strategy for determining optimal conditions. This method is a set of statistical and mathematical techniques, used for the development, improvement and optimization of some processes, in which a response of interest is affected by several process variables, whose objective is to optimize this response. To quantify the effects of influential factors and their interactions on the studied response, we identify the form of this influence by developing a mathematical equation that allows describing the studied response according to influential factors, in order to obtain a significant empirical model [9].

Several possible mathematical models are assigned to the experimental designs. The aim is to build a model that uses the action of all factors.

: Constant Term : Squarish : Squarish Term Right-angled Term? :Error Term y: is called predicted or estimated response. The latter general equation can be simplified by eliminating non-significant terms. This depends on the choice of the experimenter, according to the level of confidence in regards to the model, which allows obtaining a reduced equation.

3 III.

4 Software Used

The statistical and graphical analysis software used in this study to interpret the results of the experimental design is Design-expert 7 version 7.0.0.

e-mail: a.alouani@ocpgroup.ma Let $X_1, X_2, \dots, X_k$ be the k factors and Y the response. The model is written in the following form: $Y = \mu + \sum_{i=1}^k \mu_i X_i + \sum_{i=1}^{k-1} \sum_{j=i+1}^k \mu_{ij} X_i X_j + \dots + \mu_{12\dots k} X_1 X_2 \dots X_k + \epsilon$: Linear Term $\mu_i X_i$: Quadratic Term $\mu_{ii} X_i^2$: Cubic Term $\mu_{iii} X_i^3$: Four-way Interaction Term $\mu_{ijkl} X_i X_j X_k X_l$: Error Term ϵ

The problem is to determine the values of the coefficients b_0, b_i, b_{ii} and b_{ij} of the model. Thus, it is necessary to carry out more than k experiments. Flotation is a process of separating precious minerals from the gangue, based on the differences in the surface properties of the particles, using reagents added in the presence of air bubbles. The consumption of flotation reagents represents a very important part in the mineral enrichment cost. In this study of optimizing the mineral flotation reagents consumption, we have empirically modeled the concentrate contents according to the influence of elements, based on the experimental designs theory [4].

The purpose of this study is to determine the optimal experimental conditions, in order to study the main effects of the different parameters and the effects of possible interactions between them, which cannot be revealed by conventional methods. The method of factorial design was applied to optimize the specific consumption of flotation reagents [5][6][7].

The flotation tests are based on the fixation of the specific concentration of two reagents and changing the third, in order to identify the test that leads to maximum percentage of concentrate y (useful product) and minimum undesirable products (impurities).

5 F

It is then possible to calculate only an estimation of the coefficients b , denoted b , calculated by the method of the least squares. The estimated model equation is then written: The important parameters which affect the concentrate y (%) are the flotation reagents R_1 (g/t), R_2 (g/t) and R_3 (g/t) [8]. The other parameters are assumed to be constant by working on the same ore quality with laboratory tests. These parameters were respectively coded x_1, x_2 and x_3 , and were studied between two levels -1 (low level) and +1 (high level). A. Alouani, A. Arbaoui, K. Benkhoulja, A. Khmich, Y. Alouani, K. Sbaili &

IV.

6 Experimental Design

Table 1: Coded and natural levels of independent parameters used. This complete polynomial model is obtained by the multiple regression technique for three factors. Most of the time, the regression method is based on the least squares optimization criterion. We obtain the most probable estimates of the coefficients we denote by: Where X is the experiment matrix, X^T the transpose of X and $(X^T X)^{-1}$ is the inverse of the matrix $(X^T X)$.

The values of the coded variables according to natural variables are defined as follows:

V. Where x_i is the coded value of the independent variable i , X_i the natural value of the independent variable i , and X_0 is the natural value of the i th independent variable at the central point.

7 Experimental Design Results

8 N° Exp.

9 Natural Values

Concentrate(%) Residuals (%) $x_1, x_2, x_3, X_1, X_2, X_3, -1, -1, -$

10 J

11 Parameters

The general equation of the model for the response Y (concentrate) in percentage is in the form:

Where y is the observed response, b_0, b_i and b_{ij} represent respectively the constant term, the coefficients of the linear terms and the terms representing the interactions between variables and ϵ that represents the residual error.

In order to test the validity of the model, the variance analysis (ANOVA) was used to examine the significance and adequacy of the model. This latter makes it possible to plot the response surfaces and to estimate the interaction between the different factors and their influence on the concentrate.

To find the optimum conditions for the y concentrate (%), the experiments were designed using the experimental design methodology. For our tests, the three independent variables chosen for this study are: R_1 (g/t), R_2 (g/t) and R_3 (g/t). The ranges and levels of these parameters are represented in coded and natural values (x_i, X_i) in table 1, therefore, it would take two levels for each factor. This makes a total of 8 necessary experiments, for a polynomial model of individual effects and interactions between the three factors. The matrix defining the conditions of the three-variable experiments is presented in table 1. $y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3$

12 Coded Values

The results of the factorial design experiments are represented in table 2 which shows the statistical combinations of independent variables x_1 (R_1 (g/t)), x_2 (R_2 (g/t)) and x_3 (R_3 (g/t)). y Experimental y calculated (g/t) (g/t) (g/t)

This software was used to analyze the regression of the data obtained and to estimate the coefficients of the regression equation [10]. In Figure ??, the plot of the experimental response is given as a function of the calculated one, in which we notice a strong correlation between the calculated response and that estimated by the model.

VI. Determining The Model Significant Terms

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From figure 1 we notice that the significant effects are A, B, C, AB and AC, which are respectively R_1 , R_2 , R_3 , the interaction $R_1 - R_2$ and the interaction $R_1 - R_3$. These parameters are the only ones that affect the response of the concentrate (%), so the empirical model is a function of the factors' individual effects and the previous interactions. $.011583 R_1 + 2.7510 R_2 + 7.510 R_3 + 3.7510 R_1 R_2 + 9.16667 R_1 R_3$

According to natural factors Design-Expert classifies the absolute values of effects from the bottom up and builds a plot of halfnormal probability. Significant effects fall to the right on this plot. To the right, select the most important effects. Look for a final gap between the guardians and the many trivial effects near zero. On the other hand, if the effects are negative, a reduction in response occurs at a high level of the same factor [11], and a positive value indicates a synergistic effect that promotes optimization [12].

The actual values of the response y_{exp} are compared to the calculated values y_{cal} by the model and their differences are called residuals. These residuals allow verifying the model quality. They are shown in figure ?? The correlations between the theoretical and experimental responses we obtained are satisfactory [13]. The determination coefficient (0.9989) is close to the unit (statistical tests).

The differences between the experimental and calculated responses (residuals) do not exceed 0.13%, which is due to experimental results variability because of manipulation. These residuals are distributed equally in space [14]. The model was accepted. Moreover, this illustrates that this polynomial model describes well the studied phenomenon and shows a good adjustment of the experimental results.

J b) Residuals normal probability

The normality of the data can be verified by plotting a plot of residuals normal probability. If the data points on the ground fall close enough to the straight line, the data is normally distributed [15].

Figure 4: Residuals Probability

The results of the concentrate y (%) variance analysis are given in Table 3: It appears from these results that:

-The Model F-value of 348.12 implies the model is significant. There is only a 0.29% chance that a "Model F-Value" this large could occur due to noise; -Values of "Prob > F" less than 0.0500 indicate model terms are significant [16]; -

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The residuals normal probability graph is given in figure ?. We find that in the response in concentrate function y (%), the data points are close enough to the straight line and this indicates that the experiments arise from a normally distributed population. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable [17]. Your ratio of 55.948 indicates an adequate signal. This model can be used to navigate the design space.

VIII. Comparison Between the Empirical Model Responses and Experimental Ones

According to this curve, we notice that the response of the concentrate y (%) found starting from the empirical model are identical to those found in the laboratory with the same elaboration conditions. In other words, they are similar for most tests. Therefore, we infer that there is a strong correlation between the experimental and empirical models responses. The study of contour graphs provides a simple method of optimizing the rate of treatment, and identifying interactions between variables (Figs. 6-9). Each curve represents, in our case, the combinations between two variables when the third variable is maintained at a constant level. These constant levels are the central levels of each variable.

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Based on the experimental responses found in the laboratory and the responses calculated by the empirical model and their differences, i.e. the residuals (table 2), we can plot the figure 5 that illustrates the comparison between these responses (experimental and model) for the 8 tests.

For the interaction R 1 -R 2 , the response surface of figure 6 shows that the concentrate y (%) increases progressively with the increase of the values of R 2 and R 1 . The contour graph (figure 7) illustrates well these variations.

The 3D response surface is a three-dimensional graphical representation, it was used to determine the individual and cumulative effect of the mutual interaction between the variables [18]. The response surface analyzes the geometric nature of the surface, the maxima and minima of the response. The contour graph plot by this model is a graphical technique to represent a three-dimensional polynomial response surface by plotting z-slices on a two-dimensional format. Lines are plotted to connect the coordinates (x, y) where this zvalue occurs [19]. Figures 8 and 9 show that there is a strong interaction R 1 -R 3 . Indeed, the response surface indicates that the concentrate y (%) increases progressively with the increase of R 1 and R consumption.

21 3

To validate these interpretations, figures 10 and 11 illustrate the concentrate y (%) maximum value obtained according to maximum consumption of flotation reagents.

The increase of the concentrate y (%) with the increase in consumption of R 1 , R 2 and R 3 is linked to several approaches; to the power of depression and of the concentrate particles because of the strong adsorption of R 1 on their surfaces that increases their masses and ensures their gravity in the recovered non-float product. This increase is due both to the strong collection of undesirable elements with R 2 and R 3 that improves their hydrophobicities and ensures their affinities with the air bubbles injected into the flotation pilot cell [20][21]. The undesirable elements are transported to the surface forming a foam (floating product) rich in percentages of undesirable elements. This migration or evacuation of the collected elements ensures an increase in the percentage of the concentrate particles in the non-floating product and thereafter the increase of the concentrate y (%) in the product (non-floating). Theory and Practice of Minerallurgy?, 1st English This study has shown that the experimental design methodology allows developing an empirical model that allows a good understanding and describing, in a satisfactory way of the concentrate y (%) at every point of the experimental field. The influence of R 1 (g/t), R 2 (g/t) and R 3 (g/t) was performed on the concentrate y (%). The results show that the optimization and modeling of the concentrate y (%) using the factorial design method allows us to correctly describe the influence of these three experimental parameters on the effectiveness of the treatment. Statistical analysis showed that the two interactions R 1 -R 2 and R 1 -R 3 are the most influential ones. This study shows that the model used is highly significant and in accordance with the experimental results. This is convenient with approximations or appropriate approaches with the interpretations in the previous paragraph.

22 Conclusion Bibliographic References

In order to improve the flotation process overall performance, several flow recycling case studies were considered. The reduction of the recycling ratio increases the specific consumption of Flotation reagents, however its progressive increment reduces the need for reagents up to an optimal level. Moreover, any increase results in an accumulation of fine particles in the circuits, which causes saturation and a reduction of the production capacity in the Flotation unit. According to the "AA" curve below, the industrial optimization led to a remarkable reduction of the specific consumptions for the same raw product profile and for the same level of the production capacity [22]. edition, Oficyna Wydawnicza PWr, Wroclaw University of Technology. (2007) 344-362. We can conclude, through these figures analysis, that the flotation process using important consumption of reagents (g/t) (R 1 , R 2 and R 3) allows obtaining high concentrate values which reach 71.7%.¹

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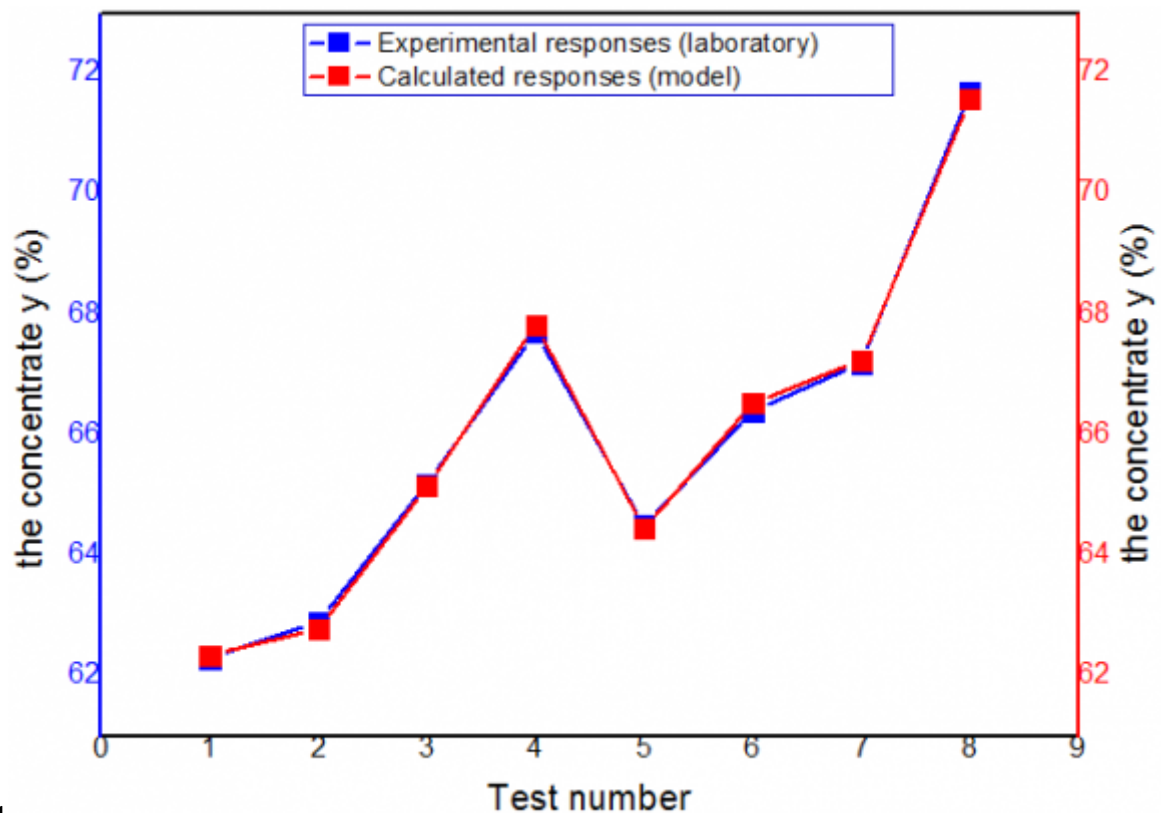


Figure 1: Figure 1 :

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science, EI Jadida, Morocco
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Figure 2:

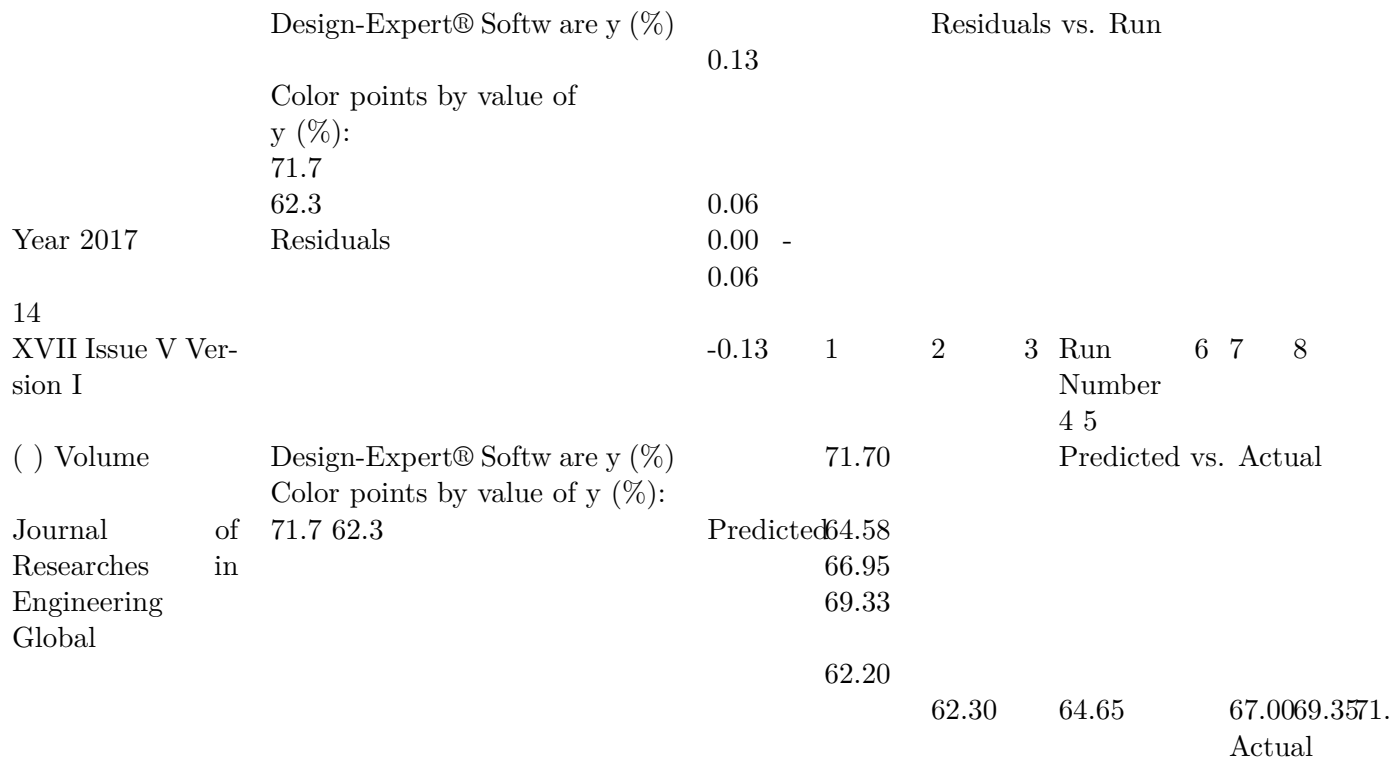
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Optimization of Flotation Reagents' Specific Consumption, by Modeling During Mineral Enrichment		
	Coded and natural levels	
	-1	+1
X 1 : R 1 (g/t)	300	600
X 2 : R 2 (g/t)	200	400
X 3 : R 3 (g/t)	60	120
$\hat{a} = (?? ?? ??) ??? ?? ?? ??$		
t		
t -1		

Figure 3: Table 2 :

Design-Expert® Softw	99	Half-Normal	Year 2017
are y (%) A: R1 (g/t)		Plot	
B: R2 (g/t)			
C: R3 (g/t)			
Positive Effects	Half-	0 10 0.00	Standardized C 3.92
Negative Effects	Normal	20 30 0.98	() Volume XVII Is-
	%	50 70 1.96 2.94 A	sue V Version I 13
	Prob-	80 90 AB AC	
	abil-	95	
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			nals
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Figure 4:



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Figure 5:

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Source	Freedom de- gree	Mean squares	F-value	p-value Prob>F	Signification
Model	5	12.62	348.12	0.0029	Significant
A-R 1	1	11.28	311.21	0.0032	Significant term
B-R 2	1	30.81	849.97	0.0012	Significant term
C-R 3	1	17.11	472.03	0.0021	Significant term
AB	1	2.53	69.83	0.0140	Significant term
AC	1	1.36	37.55	0.0256	Significant term

Figure 6: Table 3 :

186 [Sheridan et al.] , M S Sheridan , D R Nagaraj , D Fornasiero , J Ralston . (?The use of a factorial experimental
187 design)

188 [Miner. Eng ()] , *Miner. Eng* 2002. 15 p. .

189 [Meloun et al. ()] ‘?Crucial problems in regression modelling and their solutions?’. M Meloun , J Militky , M Hill
190 , R G Brereton . *Analyst* 2002. 127 p. .

191 [Antony ()] *?Design of experiments for engineers and scientists?*, J Antony . 2003. New York: Butterworth-
192 Heinemann.

193 [Bradshaw et al. ()] ‘?Development of methodologies to improve the assessment of reagent behaviour in flotation
194 with particular reference to collectors and depressants?’. D J Bradshaw , B Oostendorp , P J Harris . *Miner.*
195 *Eng* 2005. 18 p. .

196 [Korbahti and Tanyolac ()] ‘?Electrochemical treatment of simulated textile wastewater with industrial compo-
197 nents and Levafix Blue CA reactive dye: optimization through response surface methodology?’. B K Korbahti
198 , A Tanyolac . *Journal of Hazardous Materials* 2008. 151 p. .

199 [Mäkelä ()] *?Experimental design and response surface methodology in energy applications: A tutorial review ?*,
200 *Energy Conversion and Management*, M Mäkelä . 2017. 151 p. .

201 [Barka et al. ()] ‘?Full factorial experimental design applied to oxalic acid photo catalytic degradation in TiO₂
202 aqueous solution?’. N Barka , M Abdennouri , A Boussaoud , A Galadi , M Baâlala , M Bensitel . *Arab. J.*
203 *Chem* 2014. 7 p. .

204 [Nayak et al. ()] ‘?Ispaghula mucilage gellan mucoadhesive beads of met form in HCl: Development by response
205 surface methodology?’. A K Nayak , D Pal , K Santra . *Carbohydr. Polym* 2014. 107 p. .

206 [Karger et al. ()] ‘?Nomenclature recommendations for adsorptive bubble separation methods?’. B L Karger , R
207 B Grieves , R Lemlich , A J Rubin , F Sebba . *Sep. Sci* 1967. 2 p. .

208 [Tan et al. ()] ‘?Optimization of partitioning process parameters of chloramphenicol in ionic liquid aqueous two-
209 phase flotation using response surface methodology?’. Z Tan , S Song , J Han , Y Wang , Y Lu , Y Yan . *J.*
210 *Iran. Chem. Soc* 2013. 10 p. .

211 [Nanthakumar and Kelebek ()] ‘?Stagewise analysis of flotation by factorial design approach with an application
212 to the flotation of oxidized pentlandite and pyrrhotite?’. B Nanthakumar , S Kelebek . *Int. J. Miner. Process*
213 2007. 84 p. .

214 [Alouani et al. ()] ‘?The Mineral Flotation Overall Performance Increase by the Improvement of Recycling?’. A
215 Alouani , K Arbaoui , Benkhoucha . *Global Journal of Researches in Engineering* 2017. 17 p. 3.

216 [Anderson et al. ()] M J Anderson , P J Whitcomb , Doe Simplified . *?Practical Tools for Effective Experimentation*
217 *Productivity Press?*, (New York, NY, USA) 2000.

218 [Smar and Klimpel ()] ‘Aplan, ?Evaluation of chemical and operational variables for the flotation of a copper
219 ore Part I-collector concentration, frother concentration, and air flow rate?’. V D Smar , R R Klimpel , FF .
220 *Int. J. Miner. Process* 1994. 42 p. .

221 [SM ()] ‘Bulatovic, ?Handbook of Flotation Reagents, Chemistry, Theory and Practice: Flotation of Sulfide
222 Ores?’. SM . *Science & Technology Books* 2007. Elsevier. 1 p. .

223 [R ()] ‘Lemlich ?Adsorptive bubble separation methods?’. R . *Ind. & Eng. Chem* 1968. 60 p. .

224 [Abaamrane et al. ()] *Modeling of photocatalytic mineralization of phthalic acid in TiO₂ suspension using*
225 *response surface methodology (RSM)” Water Treat*, S Abaamrane , M El Qourzal , S Ouadi , M Alahiane ,
226 H Belmouden , N Bari , S Barka , A Billah , Y Assabbane , Desalin Ait-Ichou . 2015. 53 p. .

227 [Nayak ()] ‘Pal, ?Development of pH-sensitive tamarind seed polysaccharide-alginate composite beads for
228 controlled diclofenac sodium delivery using response surface methodology?’. A K Nayak , D . *International*
229 *Journal of Biological Macromolecules* 2011. 49 p. .

230 [Hooda et al. ()] ‘Rathee, ?Optimization and evaluation of gastroretentive ranitidine HCl microspheres by using
231 design expert software?’. A Hooda , A Nanda , M Jain , V Kumar , P . *Int. J. Biol. Macromol* 2012. 51 p. .