Maejo Int. J. Sci. Technol. **2010**, *4*(03), 397-404

Maejo International Journal of Science and Technology

ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Full Paper

Effects of modulus and dosage of sodium silicate on limestone flotation

Danda S. Rao[1,*], Tadiparthi V. Vijayakumar[2], Shivakumar Angadi[1], Swarna Prabhakar[2] and Guntamadugu B. Raju[2]

[1] Institute of Minerals and Materials Technology, Bhubaneswar - 751 013, Orissa, India
[2] National Metallurgical Laboratory - Madras Centre, CSIR Madras Complex, Taramani, Chennai – 600 113, India
* Corresponding author, e-mail: dsrao@immt.res.in

Received: 15 April 2010 / Accepted: 15 September 2010 / Published: 21 September 2010

Abstract: Sodium silicates are probably one of the oldest and most widely used industrial chemicals. Among a wide variety of applications, an important one is as a depressant in flotation. In this investigation, the effectiveness of sodium silicates of different values of modulus (silica-to-soda ratio) and dosage was investigated on a low-grade siliceous limestone sample having CaO = 45.10%, SiO_2 = 15.60% and LOI = 36.03% from Jayantipuram mine of Andhra Pradesh, India. Direct flotation (flotation of carbonate minerals) was adopted to reduce the silica content and enrich CaO using laboratory-scale flotation process batch tests. The analysis of variance (ANOVA) statistical tool was used for evaluation of the influence of operating parameters, viz. the modulus and dosage of sodium silicate, on the flotation. The study indicated that a modulus of 2.19 and a dosage of 0.6 kg/ton is optimum for the flotation for the low-grade siliceous limestone sample.

Keywords: siliceous limestone, direct flotation, sodium silicate, mineral depressant

Introduction

One of the most important groups of chemicals used in mineral processing is the depressant. Most often, the flotation separation of individual minerals from ores is not possible without the use of a depressant. Depressants affect the flotation process by rendering the gangue mineral hydrophilic, thus reducing the possibility of the unwanted minerals being floated simultaneously with those substances which are to be concentrated in the froth. Substances used as gangue mineral depressants in flotation process cover a large variety of both organic and inorganic chemicals and these are well documented in the literature. The type of depressant used largely depends on the variety of mineral substances which accompany the ore. Sodium silicate is one such chemical which is widely used as depressant in the flotation in general and non-sulphide mineral flotation in particular. Sodium silicate is a versatile, non-toxic as well as a low-cost multifaceted chemical available in many forms and for a wide range of industrial applications [1]. In the case of mineral beneficiation, sodium silicate is used as a depressant [2-6] as well as a dispersant [7-9] . In some cases, it is also used as an activator [10] because it reduces or eliminates the deleterious/depressing effects of slimes on flotation. In also helps in grinding [11] because it lowers the viscosity and/or provides finer grinding or increases throughput for the same particle sizes.

Sodium silicate is also called water glass and has a composition expressed by $mNa_2O.nSiO_2$. The ratio n/m is referred to as the modulus of sodium silicate. The type frequently used in flotation has a modulus varying between 1.5-3.0 [12-13]. In flotation, the action of sodium silicate depends largely on the pH of the medium/slurry, the concentration of the depressant, the oxygen potential of the medium/slurry and the presence of other reagents. The action of the depressant also depends upon the mineral composition of the ore, its particle size and flotation parameters such as extent of conditioning, stirring and flotation time [14-15].

References on flotation employing sodium silicate are often inadequate because they failed to mention the type of sodium silicate used or its modulus . In this investigation, experiments have been conducted with three different types of sodium silicate to determine its effects of type and dosage or concentration on the recovery of a siliceous limestone sample from Jayantipuram mine of Andhra Pradesh, India. Rao et al. [16] studied a siliceous limestone sample from the same area and reported that direct flotation, in which the gangue is depressed and the useful mineral is floated, gives a better result than reverse flotation. Thus, in the present undertaking, different types of sodium silicate are studied using the same method to find out which may give rise to better results. Of course, the choice of sodium silicates is also dictated by the relative costs of the sodium silicates and other considerations.

Materials and Methods

The low-grade siliceous limestone sample used in this study was obtained from Jayantipuram mine of Andhra Pradesh, India. The bulk constituents of the sample, as analysed by conventional chemical analysis methods, was 45.10% CaO, 15.60% SiO_2 and 36.03% LOI (loss on ignition). Oleic acid and sodium hydroxide used for preparation of sodium oleate were of laboratory grade reagents. Sodium silicate and sodium oleate were used as depressant and collector respectively. Sodium silicates used were of commercial grade and procured from Kiran Pondy Chems Limited, Chennai. Table 1 gives details of the different types of sodium silicate.

The feed particle size distribution of the siliceous limestone sample obtained with a laboratory ball mill and used for the flotation experiments is presented in Table 2. . It can be observed from the table that 80% of the feed material (d_{80}) was 68 microns or finer. Bench-scale conventional flotation tests were performed with a D12 Denver flotation machine (Denver Equipment Company, England). The sequence of addition of reagents was as follows:

Maejo Int. J. Sci. Technol. **2010**, *4*(03), 397-404

- Tap water (1 litre, pH ≈ 7.0) was added first along with the feed (500 g).
- Required dosage of sodium silicate in solution form (10% w/v) was added to the above and the mixture conditioned for 3 minutes. Then sodium oleate (0.1 g) was added to the system, which was further conditioned for another 3 minutes.
- Natural pH was maintained throughout the flotation experiment. After 10 minutes of flotation, float and non-float products were filtered, dried, weighed and analysed for CaO, SiO_2 and LOI.

Table 1. Types of sodium silicate [1]

Type	1	2	3
Specific gravity	1.56	1.56	1.49
Na_2O	14.76	13.82	12.04
SiO_2	32.31	33.16	31.30
Total solid	47.09	46.98	43.34
SiO_2/ Na_2O	2.19	2.49	2.60
Nature	Alkaline	Alkaline	Alkaline
Cost per ton	Rs.8750/-	Rs.8750/-	Rs.8750/-

Table 2. Size distribution of siliceous limestone sample

Size in micron	Weight (%)	Cum wt (%)
+212	1.3	98.7
-212+150	2.7	96.0
-150+106	7.3	88.7
-106+75	4.3	84.4
-75+63	5.1	79.3
-63+45	45.3	34.0
-45	34.0	0.0
	100.0	
d_{80} = 68 microns		

Rao et al. [16] studied the siliceous limestone sample from the same area and reported that the sodium oleate dosage of 0.2 kg/ton and water at pH 7 gives the best results. Thus, in all our experiments the pH of the flotation slurry was kept natural (~7) and the sodium oleate dosage of 0.2 kg/ton was used. A series of experiments were carried out by varying the modulus of sodium silicate and its dosage at three levels as shown in Table 3.

Table 3. Experimental variables and their levels

Variable	Level 1	Level 2	Level 3
Modulus of sodium silicate	2.19	2.40	2.60
Dosage of sodium silicate (kg/ton)	0.6	1.0	1.4

Maejo Int. J. Sci. Technol. **2010**, *4*(03), 397-404

Results and Discussion

A systematic approach has been made to assess the effectiveness of recovering the limestone from a low-grade siliceous ore. All experiments carried out at different values of modulus and dosage of sodium silicate are presented in Table 4.

Table 4. Flotation experimental results

Expt. no.	Modulus of sodium silicate	Dosage of sodium silicate (kg/ton)	Product	Yield (% weight)	CaO (%)	SiO_2 (%)
1a	2.19	0.6	Froth	81.2	**51.36**	**5.44**
			Non-froth	18.8	18.06	59.48
2a	2.40		Froth	81.9	51.18	5.66
			Non-froth	18.1	17.59	60.60
3a	2.60		Froth	82.6	50.98	5.71
			Non-froth	17.4	17.26	62.42
1b	2.19	1.0	Froth	82.2	51.14	5.74
			Non-froth	17.8	17.22	61.13
2b	2.40		Froth	83.2	50.98	6.03
			Non-froth	16.8	15.98	62.99
3b	2.60		Froth	**84.3**	50.70	6.16
			Non-froth	15.7	15.04	66.29
1c	2.19	1.4	Froth	81.7	51.05	6.07
			Non-froth	18.3	18.54	58.15
2c	2.40		Froth	82.5	50.76	6.41
			Non-froth	17.5	18.42	58.92
3c	2.60		Froth	83.2	50.16	6.58
			Non-froth	16.8	20.04	60.28

The common indicators used for the evaluation of performance of a limestone flotation operation are yield (% weight), % CaO and % SiO_2 of the products. The flotation operation is said to be optimum when it produces a maximum yield of the froth fraction with a high CaO content and a low SiO_2 content. A change in the level of reagents is seen to affect both yield and CaO and SiO_2 contents. In the present context, the effects of sodium silicate modulus and dosage on the product yield (% weight %), % CaO and % SiO_2 are analysed.

Effects of operating variables on product yield

Table 5 presents the results of a statistical analysis of the effects of the reagent modulus and dosage on the product yield. The analysis of variance (ANOVA) shows that calculated values of ‘F’

(F- ratio) for both silica-to-soda ratio (R) and dosage (D) are higher than the P values. This means that both modulus and dosage increase the yield of limestone. Further it can be inferred from the table that the effect of modulus (R) plays more prominent role than that of dosage (D) as the calculated F-ratio value for the former is higher than that for the latter.

With an increase in sodium silicate dosage, the % weight of the product concentrate (froth fraction) increases to certain level and again falls down, indicating that the unliberated calcite (with quartz) gets depressed, whereas with an increase in the reagent modulus, the % weight of the product concentrate always increases (Figure 1), although its grade (% CaO) is lowered (Table 4). The sodium silicate with a modulus of 2.19 gives the highest CaO content (51.36%) and lowest SiO_2 content (5.44%) in the froth fraction, with only 0.6 kg/ton dosage of the reagent. On the other hand, the dosage variation indicated that sodium silicate with a modulus of 2.6 gives the highest recovery of the froth fraction (84.3%) with 1.0 kg/ton dosage, but the grade of the product is lower than that obtained using sodium silicate with 2.19 modulus at 0.6 kg/ton dosage. From the economic point of view, the use of 0.6 kg/ton of the sodium silicate with 2.19 modulus should be more preferable since it gives a better grade of the product with comparable yield, while the cost of all three sodium silicate varieties is the same.

Table 5. Results of analysis of product yield (% weight) by ANOVA

Source	Sum of square	df	Mean square	F- ratio	P
R	4.167	2	2.083	56.3	19.0
D	2.687	2	1.343	36.3	19.0
Error	0.147	4	0.037		

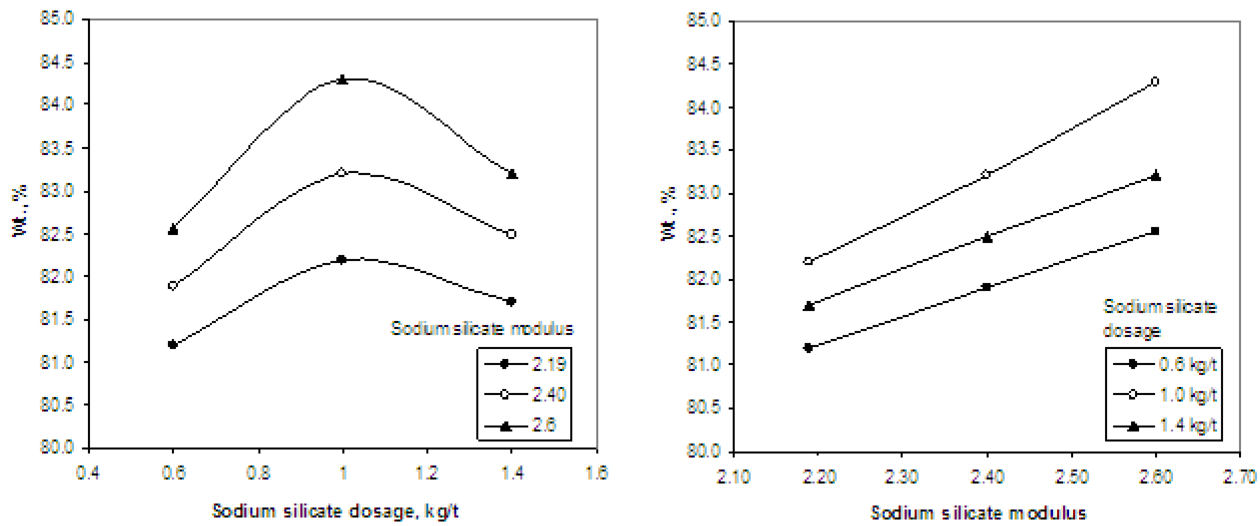

Figure 1. Influence of sodium silicate modulus and dosage on product yield (% weight)

Effects of operating variables on % CaO

Sodium silicate is used in flotation to depress and/or disperse silicate minerals, as a result of which CaO content in the froth product is enriched. In the present case, however, increase of sodium silicate dosage and modulus decreases the CaO content in the froth concentrate (Figure 2). This could be because of the association of fine silicate gangue minerals present as inclusions within the limestone minerals.

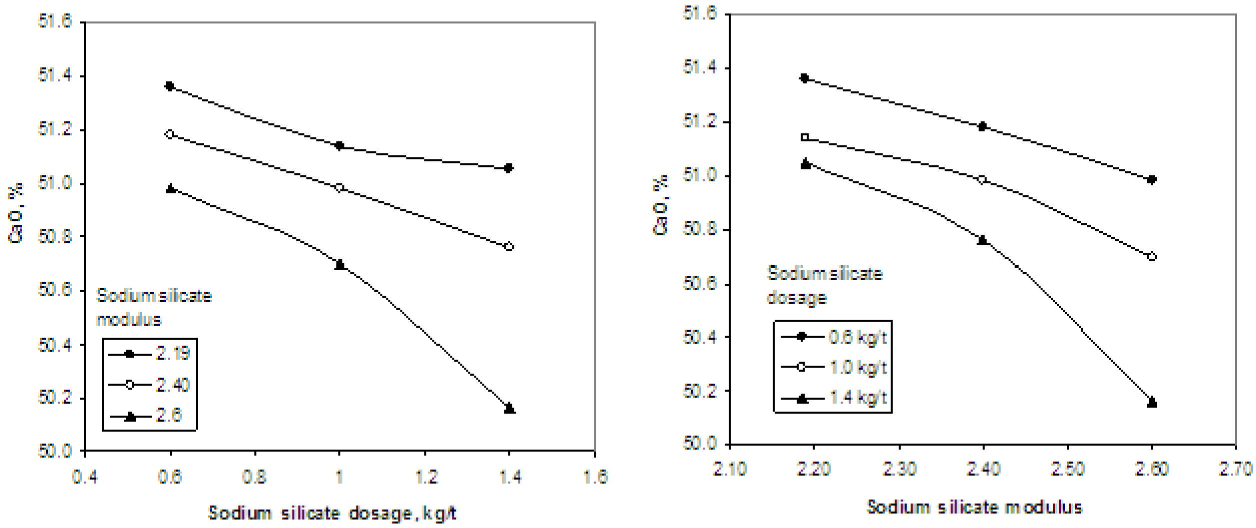

Figure 2. Influence of sodium silicate modulus and dosage on % CaO of froth concentrate

The effects of the reagent modulus and dosage on CaO content of the froth fractions were analysed statistically and the results are presented in Table 6. The analysis of variance (ANOVA) shows that calculated values of 'F' (F-ratio) for both sodium silicate modulus (R) and dosage (D) are lower than the P values. This means that neither modulus nor dosage of the regent is prominently influencing the CaO content of the concentrate.

Table 6. Results of analysis of % CaO by ANOVA

Source	Sum of square	df	Mean square	F-ratio	P
R	0.499	2	0.249	11.9	19.0
D	0.402	2	0.201	9.6	19.0
Error	0.085	4	0.021		

Effects of operating variables on % SiO_2

Similar effects of the reagent modulus and dosage on the SiO_2 content of the product were analysed statistically and the results are presented in Table 7. The analysis of variance (ANOVA) shows that calculated values of 'F' (F-ratio) for both sodium silicate modulus (R) and dosage (D) are lower than the P values. This means that neither modulus nor dosage of the reagent is prominently influencing the SiO_2 content of the concentrate (Figure 3).

Maejo Int. J. Sci. Technol. **2010**, *4*(03), 397-404

Table 7. Results of analysis of % SiO_2 by ANOVA

Source	Sum of square	df	Mean square	F-ratio	P
R	0.255	2	0.127	1.7	19.0
D	0.167	2	0.084	1.1	19.0
Error	0.299	4	0.075		

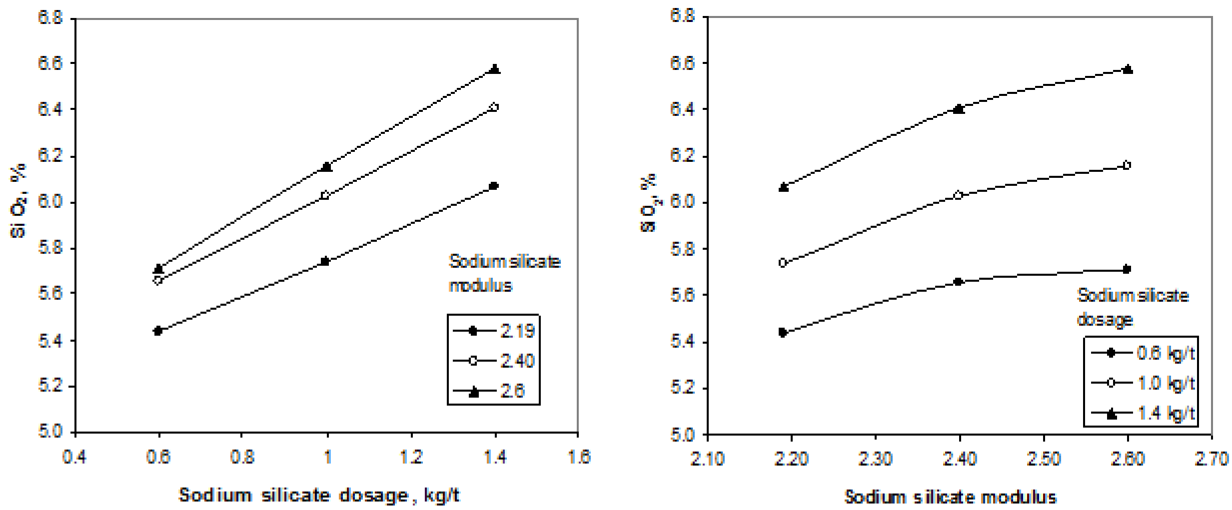

Figure 3. Influence of sodium silicate modulus and dosage on % SiO_2 of the froth concentrate

Conclusions

This study has revealed that both the modulus and dosage of sodium silicate have an influence on the yield of the flotation product of a low-grade siliceous limestone ore. As the modulus increases, so does the yield, whereas a miximum yield occurs at an intermediate dosage of sodium silicate. As the yield increases, however, a somewhat lower grade of product is obtained.

Increase of sodium silicate modulus and dosage tends to decrease the CaO content of the flotation product while the SiO_2 content is increased. However, both of these variables were found to have less influence on the CaO and SiO_2 contents compared with that on the yield of the product.

Acknowledgements

The authors are thankful to the Director of National Metallurgical Laboratory, Jamshedpur for his valuable guidance, encouragement and permission to publish this work. The authors would also like to thank M/s. Madras Cements Limited for providing logistic support, and Chennai and Ramco Research and Development Centre, Chennai for providing chemical analysis of the limestone samples.

References

1. R. C. Merrill, "Industrial applications of the sodium silicates—some recent developments", *Ind. Eng. Chem.*, **1949**, *41*, 337-345.
2. B. C. Acharya, D. S. Rao and P. S. R. Reddy, "Mineralogical and beneficiation characteristics of low grade graphite ores", *Powder Handl. Process.*, **1995**, *7*, 233-237.

Maejo Int. J. Sci. Technol. **2010**, *4*(03), 397-404

3. B. C. Acharya, D. S. Rao, S. Prakash, P. S. R. Reddy and S. K. Biswal, "Processing of low grade graphite ores of Orissa, India", *Miner. Eng.,* **1996**, *9*, 1165-1169.
4. D. Ananth, N. N. Gothe and S. Subramanian, "Studies on beneficiation of limestone from Salem", *J. Mines Metals Fuels*, **1997**, *45*, 216-219.
5. S. Rao, B. V. Narayana and S. Subramanian, "Optimization studies on limestone beneficiation', *Ind. J. Eng. Mater. Sci.*, **1997**, *4*, 139-144.
6. J. R. de Wet and J. D. Singleton, "Development of a viable process for the recovery of zinc from oxide ores", *J. South Afr. Inst. Miner. Metall.,* **2008**, *108*, 253-259.
7. R. Asmatulu, "Removal of the discoloring contaminants of East Georgia kaolin clay and its dewatering", *Turkish J. Eng. Env. Sci.*, **2002**, *26*, 447-453.
8. J. Pauck and J. Marsh, "The role of sodium silicate in the flotation deinking of newsprint at Mondi Merebank", *Tappsa J.*, Jan. **2002**, 20-25.
9. M. O., Silvestre, C. A. Pereira, R. Galery and A. E. C. Peres, "Dispersion effect on a lead–zinc sulphide ore flotation", *Miner. Eng.*, **2009**, *22*, 752-758.
10. M. C. Fuerstenau and K. N. Han, "Activators", in "Reagents in Mineral Technology: Surfactant Science Series" (Ed. P. Somusundaran and B. M. Moudgil), **1987**, *27*, 411-427.
11. Y. Cebeci and O. Bayat, "Effect of flotation reagents on the wet grinding of celestite concentrate", *Ind. J. Chem. Tech.*, **2004**, *11*, 382-387.
12. C. L. Sollenberger and R. B. Greenwalt, "Relative effectiveness of sodium silicates of different silica-soda ratios as gangue depressants in non-metallic flotation", *Min. Eng.*, **1958**, *10*, 691-693.
13. M. C. Fuerstenau, G. Gutierrez and D. A. Elgillani, "The influence of sodium silicate in non-metallic flotation system", *AIME Trans.*, **1972**, *241*, 348-352.
14. S. P. Mehrotra and P. C. Kapur, "The effects of aeration rate, particle size and pulp density on the flotation rate distributions", *Powder Technol.*, **1983**, *9*, 213-219.
15. A. M. R. Botelho, C. T. O'Connar and R. C. Dunne, "The influence of various chemical, physical and mineralogical factors on the flotation of gold bearing pyrites", Proceedings of International Conference on Gold: 2. Extractive Metallurgy of Gold, **1986**, Johannesburg, South Africa, pp. 493-503.
16. D. S., Rao, T. V. Vijaya Kumar, S. Prabhakar and G. B. Raju, "Beneficiation of a siliceous limestone sample", *A. T. Min. Proc.*, **2009**, *50*, 36-47.