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OPTIMIZATION OF DESLIMING PRIOR TO PHOSPHATE ORE UPGRADING BY FLOTATION

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Flotation is one of the most efficient techniques applied for phosphate upgrading. Desliming of flotation feed is a critical pre-request step for successful phosphate/gangue separation by flotation. Generally, the target of the desliming step is to minimize the feed fines to avoid their negative effects during flotation. However, such slimes normally contain phosphates which are considered as losses. An effective desliming should pay attention to minimizing the losses of phosphate bearing minerals in the removed slimes and, as a second target, to keep high phosphate recovery in the flotation feed. In this paper optimization of the desliming stage to achieve both targets at-a-time was studied using different techniques at different operating conditions. The applied slimes removal techniques included screening and hydrocycloning. It was found that desliming using hydrocyclone, at its optimum operating conditions, is better than desliming using screens. This is because the deslimed product contained small amount of phosphate slimes leading to efficient separation by flotation with an overall selectivity index B=0.739 defined by formula $\varepsilon_{1,c} = (100-\varepsilon_{2,t})^{(1-B)}/100^{(-B)}$ where $\varepsilon_{1,c} = P_2O_5$ recovery in flotation concentrate, %; $\varepsilon_{2,t}$ = MgO recovery in both slimes and flotation tail, % .

Key words: desliming, phosphate, flotation, selectivity index

INTRODUCTION

Phosphate rocks are important in different industries as phosphoric acid and fertilizers (80%), and elemental phosphorous production (15% of the phosphate utilizing in the world) (El-Mahdy, 2004). They are usually upgraded to minimize their gangues before introduced to any of the mentioned applications. Different upgrading techniques can be applied for phosphate concentration. A successful phosphate-upgrading technique depends on the ore type and its geological history in addition to nature of the phosphate-associated gangue. One of the most effective and widely applied techniques for phosphate upgrading is flotation (Houot, 1982; Abdel-Khalek

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and Farrah, 2004, El-Mahdy, 2004). The technique proved its high effectiveness in upgrading siliceous phosphates when flotation is direct, reverse or in a combination of these two processes such as the Crago "Double Float" process (Yingxue et al., 1995) and its simplified reverse version (Patrick et al., 2000). In carbonaceous phosphate flotation, despite the difficulty of selective separation, yet it can be successfully achieved under strict conditions (Anazia and Hanna, 1987; Xiapeng et al., 2000).

One of the main disadvantages of phosphate upgrading by flotation is the high sensitivity of collectors to slimes. Therefore, for successful flotation, desliming is a necessary pre-request. Following this trend, the classical aim of desliming is removing fines (<37 μm or 400 mesh) from flotation feed. Unfortunately, in desliming, huge amounts of phosphate are lost in the slimes. The losses may lead to a rejection of up to 25% of the P_2O_5 mass content in some cases (Lawendy and Steven, 1993). For deeper visualization of the value of phosphate losses in the slimes, Patrick et al. (2001) showed that in Florida 180 gigagrams (Gg that is million tons) of P_2O_5 (an equivalent of 600 Gg (million tons) of phosphate rock with an average P_2O_5 content of 30%) discarded with the waste slimes in about 34 beneficiation years (1954-1987). In the year 2001 only, the losses in Florida district were evaluated to be 3.27 Gg of P_2O_5 which are equivalent to 10.9 Gg phosphate ore with an average P_2O_5 content of 27% (Patrick et al., 2001).

Keeping this in mind, research was devoted to recover the phosphate losses by re-treatment of such slimes (Patrick et al., 2001). In our opinion, it will be of more interest to minimize such losses from the beginning. Optimization of the desliming step is one of the proposed solutions to minimize phosphate losses in the slimes without effecting flotation performance. Therefore, this paper aims at studying the optimization of the desliming step to achieve two targets at-a-time, that is slimes removal with minimum phosphate disposal at constant flotation performance. The optimization will be carried out using different techniques set-to-work as classification tools. They include screens and hydrocyclones.

EXPERIMENTAL

SAMPLE CHARACTERIZATION AND PREPARATION

A low grade Egyptian phosphate sample from Abu-Tartur locality was used for this study. The run-of-mine was stepwise comminuted to 100% passing 0.25 mm screen. The prepared product was subjected to wet screening using a "Fritsch" shaker and a screen set. Each separated fraction of material was dried, weighed and its percent of total was recorded. Chemical analyses were run for both the run-of-mine and the different obtained size classes**.** Routine chemical analysis of samples was conducted using standard methods for phosphate analysis applying the “acid attack” method. Magnesium oxide was determined by atomic absorption technique (Ewing, 1975) using “Perkin-Elmer” Atomic Absorption model “Analyst 200”. Phosphorous was determined by spectrophotometric method (Scott, 1949) using “Perkin-Elmer” Spectrophotometer “model Lambda 3B”. The obtained product was deslimed at different operating conditions applying screening and hydrocycloning.

METHODS

Desliming using screening

In this series both wet and dry screening were tested for phosphate desliming. For all the investigated tests the same Fritsch shaker was used. The vibrating amplitude and screening time were kept constant at 50 Hz and 10 min respectively. Only the material flow rate was changed. The amount of material feed to the screen ranged from double layer to multiple layers of phosphate. The number of particle layers on the screen was calculated considering the average particle size of the feed and the total area of the screen. The screen products, oversize (flotation feed) and undersize (slimes) were calculated as percents on weight bases and analyzed for their P_2O_5 and MgO contents. The desliming step effectiveness was then evaluated on the bases of its flotation feed response to separation by flotation.

Desliming using hydrocyclone

A Mozely rig hydrocyclone was used for separating the fines (slimes) from the coarse phosphate. The tests conducted to evaluate the effect of cyclone parameters on the desliming of phosphate. They were run in two series. In the first series, the feed solid percent was verified stepwisely from 5-20% at a constant feeding pressure of 68.95 kPa (10 psi). While in the second series, the feeding pressure was investigated at an optimum previously determined solid percent of the feed. In each series, a feed batch was prepared to be enough for the whole run. In the first series, the cyclone was fed with the dense phosphate pulp (20% solids by weight) at constant pressure. Sampling for the first experiment was taken simultaneously from both the cyclone products for 30 s. Then, the same feed was diluted with the necessary amount of water for the second test, homogenized by circulating into the hydrocyclone. After homogenization the hydrocyclone products were sampled for the same 30 s. Both the underflow and overflow samples were analyzed for their solids content in addition to the cut size that was determined using Analysett 22 laser particle size analyzer. Finally, the underflow and overflow products were collected and prepared for chemical and mass balance analyses with underflow kept for further flotation investigation.

Evaluation of the desliming efficiency

The different deslimed products were considered as flotation feeds. All these feeds were subjected to flotation using a D-12 Denver flotation machine equipped with 0.5 dm^3 cell. The flotation parameters were adjusted at their optimum values as previously determined for the same locality by El-Mahdy (2004). The used collector in this case was sodium oleate of commercial grade of 75% obtained from Aldrich Chemicals, Germany. It was used without further purification. The collector dosage was maintained at a constant level of 1.5 kg/Mg. Analytical grade of NaOH, H_2SO_4, Na_2CO_3, and HCl were used as pH regulators. The overall separation efficiency due to desliming and flotation was evaluated using the Fuerstenau upgrading plot (Fig. 2) applying regression equation 1. This equation has a separation index B (Drzymala and Ahmed, 2005) and modified by Ahmed (2005)

$$\varepsilon_{1,c} = (100-\varepsilon_{2,t})^{(1-B)}/100^{(-B)} \quad (1)$$

where: $\varepsilon_{1,c}$ = P_2O_5 recovery in flotation concentrate, %; $\varepsilon_{2,t}$ = MgO recovery in both slimes and flotation tail, % and B is a separation index defined by Drzymala and Ahmed (2005). 0<B<1 means upgrading in concentrate, b=0 means no upgrading, and B= 1 means ideal upgrading.

RESULTS AND DISCUSSIONS

Figure 1 shows size distribution of the considered 100% -0.25 mm phosphate sample together with the P_2O_5 and MgO contents of the different fractions. It shows that the fine fractions (-0.075+0.045 and -0.045 mm) are characterized with their low P_2O_5 and high MgO contents. Thus, desliming using 0.075 mm screen can lead to 39% loss of the sample weight leading to rejection of 25.91% of the sample P_2O_5.

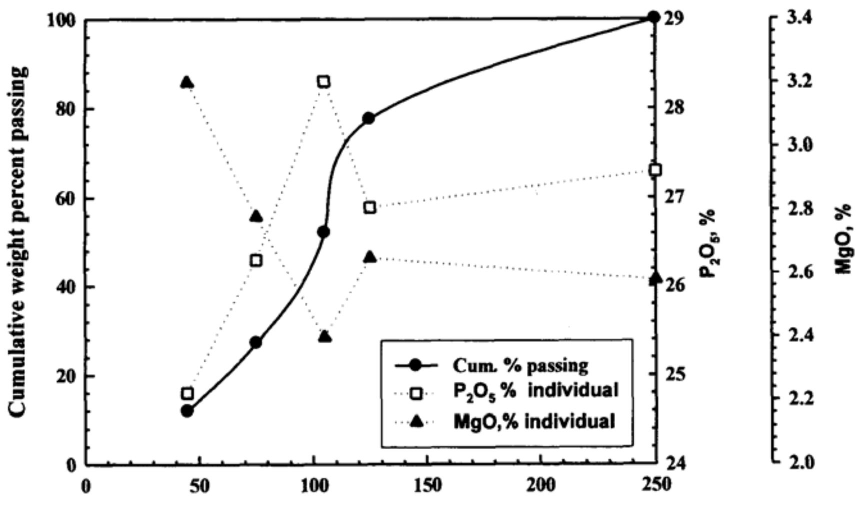

Fig. 1. Size distribution of the considered ground phosphate sample together with the individual fractions P_2O_5 and MgO contents

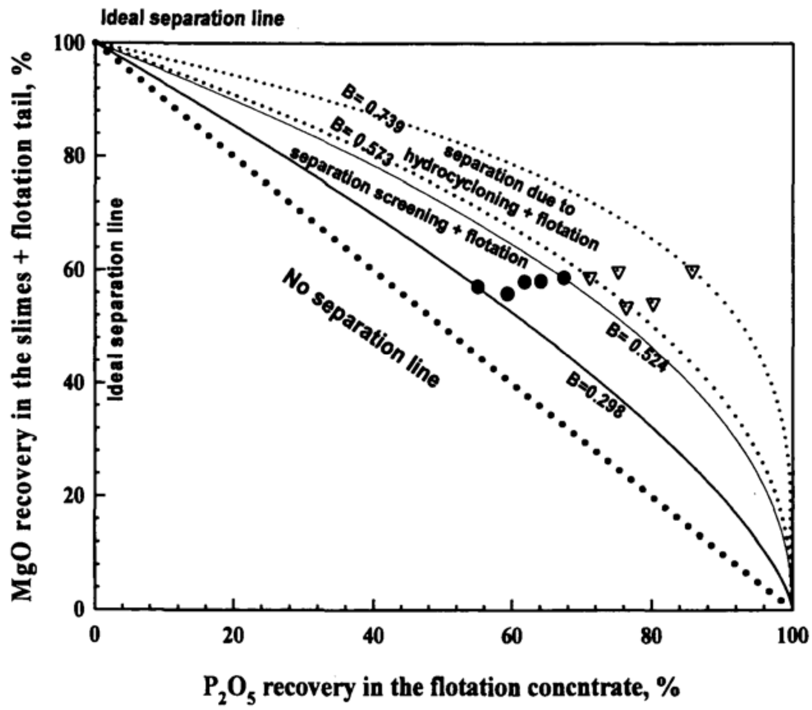

Fig. 2. Fuerstenau's plot showing effect of desliming technique on the separation efficiency of phosphate by flotation. Each point represents different desliming conditions. The results were approximated to get Drzymala-Ahmed selectivity index (parameter B in equation 1)

This loss will further increase considering the phosphate losses in the flotation tail. However, such desliming losses can be decreased to ~12 % of the sample weight with P_2O_5 rejection of 10.99 % when using a 0.045 mm screen. However, these findings reflect the importance of the cut size of the desliming stage.

SLIMES REMOVAL BY SCREENING

From the slimes phosphate content (losses) point of view, support can be given to desliming using the 0.045 mm screen. However, the screening efficiency with this fine screen depends mainly on the screening conditions. Table 1 shows the weight percent and chemical analyses of the slimes (-0.045 mm) and the flotation feed (-0.25+0.045 mm) under the investigated screening operating conditions.

In fact, the results shown in Table 1 are dangling because the phosphate losses in the slimes are minimum in some cases (exp. 5) but the flotation feed slimes seems to be still high. The relatively high fines content in the flotation feed may affect the flotation step performance. The high slimes contents of the flotation feed in the mentioned case can be attributed to an inefficient dry screening. Therefore, to judge the best of the above results, the overall phosphate losses will be evaluated after running flotation test for all of the above shown flotation feeds (feeds from 1 to 5) as will be shown later in the flotation section.

Table 1. Results of phosphate desliming using 0.045 mm screen at different mass flow rates on the screen

ID	Screening conditions	Product	Wt., %	Assay, %		Recovery, %	
				P_2O_5	MgO	P_2O_5	MgO
1	Wet screening (double solid layer)	Flotation feed (OS)	88.07	27.17	2.60	89.00	85.66
		Slimes (US)	11.93	24.80	3.21	11.00	14.34
		Calculated head	100.00	26.89	2.67	100.00	100.00
2	Wet screening (four solid layers)	Flotation feed (OS)	89.65	27.18	2.59	90.47	87.20
		Slimes (US)	10.35	24.80	3.29	9.53	12.80
		Calculated head	100.00	26.93	2.66	100.00	100.00
3	Dry screening (single solid layer)	Flotation feed (OS)	89.90	27.26	2.60	91.06	86.78
		Slimes (US)	10.10	23.83	3.52	8.94	13.22
		Calculated head	100.00	26.91	2.69	100.00	100.00
4	Dry screening (double solid layer)	Flotation feed (OS)	90.75	27.33	2.59	91.94	87.45
		Slimes (US)	9.25	23.50	3.65	8.06	12.55
		Calculated head	100.00	26.98	2.69	100.00	100.00
5	Dry screening (triple solid layer)	Flotation feed (OS)	91.17	27.19	2.61	92.07	88.54
		Slimes (US)	8.83	24.20	3.49	7.93	11.46
		Calculated head	100.00	26.93	2.69	100.00	100.00

SLIMES REMOVAL USING HYDROCYCLONE

Table 2 shows hydrocyclone products, overflow named as slimes and underflow known as flotation feed, under variable operating conditions of feeding pressure and feed solid percent. Table 2 shows that depending on the hydrocyclone operating conditions the phosphate losses in the slimes can range from 6.16 to 14.63%. It can be also noticed that the MgO recovery in the flotation feed (74-79 %) is much less compared to that of the flotation feed obtained by screening desliming (85-88 %). In fact this may be attributed to separation effect of the hydrocyclone compared to the classification effect only of screening. This is in agreement with research findings that separation of fine gangues from phosphate could be partially achieved using hydrocyclones.

Table 2. Results of phosphate desliming using Mozley hydrocyclone under different operating conditions

ID	Hydrocyclone conditions	Product	Cut size, μm	Solid, %	Wt., %	Assay, %		Recovery, %	
						P_2O_5	MgO	P_2O_5	MgO
6	Pressure = 68.95 kPa (10 psi,) Solid % = 20	Flotation feed (US)		21.48	80.35	28.68	2.45	85.37	73.46
		Slimes (OS)	65	15.60	19.65	20.09	3.62	14.63	26.54
		Calculated head		20.00	100.00	26.99	2.68	100.00	100.00
7	Pressure = 68.95 kPa (10 psi,) Solid % = 10	Flotation feed (US)		12.08	83.05	28.82	2.43	88.87	74.92
		Slimes (OS)	52	5.42	16.95	17.69	3.98	11.13	25.08
		Calculated head		10.00	100.00	26.93	2.69	100.00	100.00
8	Pressure = 68.95 kPa (10 psi,) Solid % = 5	Flotation feed (US)		6.54	87.19	28.98	2.46	93.84	79.76
		Slimes (OS)	48	1.92	12.81	12.96	4.25	6.16	20.24
		Calculated head		5.00	100.00	26.93	2.69	100.00	100.00
9	Pressure = 137.90 kPa (20 psi,) Solid % = 5	Flotation feed (US)		7.13	85.07	29.27	2.45	92.47	77.77
		Slimes (OS)	53	1.85	14.93	13.59	3.99	7.53	22.23
		Calculated head		5.00	100.00	26.93	2.68	100.00	100.00
10	Pressure = 206.84 kPa (30 psi,) Solid % = 5	Flotation feed (US)		8.01	84.37	29.23	2.47	91.41	77.78
		Slimes (OS)	59	1.65	15.63	14.83	3.81	8.59	22.22
		Calculated head		5.00	100.00	26.98	2.68	100.00	100.00

EVALUATION OF THE DESLIMING EFFICIENCY BY FLOTATION

Table 3 shows flotation response of the different deslimed products. It shows that applying screening as a desliming technique, the overall phosphate losses in both flotation tailings and slimes cannot be less than 32.4 % contained in a 40.4 % of the sample weight. In fact such losses may increase to approximately 45% contained in more than half of the sample weight if the screening step operating conditions were not appropriately selected. However, as a general rule one can confirm from the obtain results that wet screening is a better technique for phosphate desliming compared to dry screening. This can be attributed to two main reasons because wet screening is much more efficient in slimes removal in addition to the side effect of cleaning the flotation feed surface.

On the other hand, the flotation feeds deslimed using hydrocyclone at its optimum operating conditions lead to an overall-phosphate losses of 14.22% contained in approximately 27.5% of the sample weight. The worst losses in case of using hydrocyclones were also of acceptable values (29% of P_2O_5 in 39 % of the sample

Table 3. Results of phosphate flotation after desliming using screening and hydrocyclones

Flotation of screening deslimed product			Wt., %	Assay, %		Recovery, %	
				P_2O_5	MgO	P_2O_5	MgO
11	Wet screening (low solids rate)	Concentrate	59.57	30.50	1.86	67.57	41.50
		Tail	28.50	20.22	4.14	21.43	44.16
		Overall phosphate losses (slimes + tail)	40.43	21.57	3.86	32.43	58.50
12	Wet screening (double solid layer)	Concentrate	58.00	29.85	1.93	64.29	42.08
		Tail	31.65	22.28	3.79	26.18	45.12
		Overall phosphate losses (slimes + tail)	42.00	22.90	3.67	35.71	57.92
13	Wet screening (four solid layers)	Concentrate	55.40	30.08	2.05	61.93	42.22
		Tail	34.50	22.72	3.47	29.13	44.56
		Overall phosphate losses (slimes + tail)	44.60	22.97	3.48	38.07	57.78
14	Dry screening (single solid layer)	Concentrate	52.95	30.30	2.25	59.47	44.29
		Tail	37.80	23.18	3.07	32.48	43.16
		Overall phosphate losses (slimes + tail)	47.05	23.24	3.19	40.53	55.71
15	Dry screening (double solid layer)	Concentrate	49.32	30.15	2.35	55.22	43.09
		Tail	41.85	23.71	2.92	36.85	45.46
		Overall phosphate losses (slimes + tail)	50.68	23.80	3.02	44.78	56.91
Flotation of hydrocyclone deslimed product			Wt., %	Assay, %		Recovery, %	
				P_2O_5	MgO	P_2O_5	MgO
16	Pressure = 68.95 kPa (10 psi,) Solid % = 20	Concentrate	61.99	30.98	1.78	71.15	41.17
		Tail	18.36	20.90	4.71	14.22	32.29
		Overall phosphate losses (slimes + tail)	38.01	20.48	4.15	28.85	58.83
17	Pressure = 68.95 kPa (10 psi,) Solid % = 10	Concentrate	65.44	30.98	1.65	75.28	40.14
		Tail	17.61	20.77	5.31	13.58	34.78
		Overall phosphate losses (slimes + tail)	34.56	19.26	4.66	24.72	59.86
18	Pressure = 68.95 kPa (10 psi,) Solid % = 5	Concentrate	72.60	31.82	1.48	85.78	39.94
		Tail	14.59	14.86	7.34	8.05	39.82
		Overall phosphate losses (slimes + tail)	27.40	13.97	5.90	14.22	60.06
19	Pressure = 137.90 kPa (20 psi,) Solid % = 5	Concentrate	68.44	31.56	1.79	80.21	45.71
		Tail	16.63	19.85	5.17	12.26	32.06
		Overall phosphate losses (slimes + tail)	31.56	16.89	4.61	19.79	54.29
20	Pressure = 206.84 kPa (30 psi,) Solid % = 5	Concentrate	65.87	31.29	1.89	76.39	46.45
		Tail	18.50	21.90	4.54	15.02	31.33
		Overall phosphate losses (slimes + tail)	34.13	18.66	4.20	23.61	53.55

weight). Another important parameter to characterize the desliming step is the overall separation efficiency of the desliming and flotation steps. Figure 2 shows the Fuerstenau plot having the overall separation index for all the considered runs. It shows that flotation preceded by hydrocyclone desliming is more selective than flotation proceeded by screening. The separation index B range was from 0.298-0.524 in case the flotation feed was deslimed by screening. On the other hand, desliming by hydrocyclone led to separation index of 0.573 at its worst case which is higher than that obtained in case of optimum screening parameters. However, at the optimum hydrocyclone operating conditions the separation index B jumped to 0.739 which is approximately three times improvement compared to that obtained in case of desliming by dry screening.

CONCLUSIONS

The work presented here has significantly showed that phosphate desliming is an important step from the phosphate losses and flotation performance point of views. The major findings of the present investigations and their potential contributions to obtaining optimum deslimed flotation feed are:

1. The performance of phosphate upgrading by flotation is sensitive to many parameters among which the desliming method of the considered feed.
2. Even with proper operating parameters, screening can never produce an optimum deslimed flotation feed.
3. The efficient screening decreases the content of flotation feed slimes but at the same time it increases the phosphate losses in such slimes.
4. Desliming on wet screening is much more efficient than desliming carried out on dry screening bases.
5. Desliming using hydrocyclone is generally better than desliming using screening.
6. The overall separation index after the desliming and flotation steps depends significantly on the desliming method. This index was found to be 0.298 at the worst case of desliming by screening, while it was as high as 0.739 at the optimum operating conditions of desliming using hydrocyclones.

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Flotacja jest jedną z najbardziej efektywnych technik stosowanych do wzbogacania fosforytów. Odszlamianie nadawy flotacyjnej jest ważnym warunkiem wstępnym dobrej separacji fosforytów od skały płonnej. Ogólnie, celem etapu odszlamiania jest minimalizacja ilości drobnych ziarn dla uniknięcia ich negatywnego wpływu na flotację. Jednakże szlamy zawierają także fosforany, które zostają tracone. Efektywne odszlamianie powinno brać pod uwagę minimalizację strat fosforanów w usuwanych drobnych ziarnach oraz pozwolić na utrzymywanie wysokiej zawartości fosforanów w nadawie flotacyjnej. W tej pracy optymalizowano etap odszlamiania dla uzyskania obu celów jednocześnie. Użyto różnych technik badawczych stosując zróżnicowane warunki technologiczne. Jako sposób usuwania drobnych ziarn zastosowano przesiewanie i klasyfikację w hydrocyklonach. Stwierdzono, że w optymalnych warunkach odszlamianie w hydrocyklonach jest lepsze niż na sitach. Odszlamiany materiał zawiera małe ilości fosforanów i dlatego prowadzi to do efektywnej separacja za pomocą flotacji a wskaźnik selektywności B, zdefiniowany jako $\varepsilon_{1,c} = (100-\varepsilon_{2,t})^{(1-B)}/100^{(-B)}$ osiąga wartość 0.739, gdzie $\varepsilon_{1,c}$ oznacza uzysk P_2O_5 w koncentracie flotacyjnym w %, podczas gdy $\varepsilon_{2,t}$ oznacza uzysk MgO w szlamach jak i w odpadzie flotacyjnym (w %) .