POSSIBILITIES FOR PNEUFLOT FLOTATION MACHINE APPLICATION IN COPPER-PORPHYRY ORE PROCESSING PLANT

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ABSTRACT. In the current research work the pre-contact flotation possibilities for recovery of Cu and Mo from copper porphyry ores, have been evaluated. The study was conducted in the form of laboratory flotation experiments with pneumatic flotation machine – PNEUFLOT® (MBE Coal & Minerals Technology). Much attention was paid to the adjustable parameters of the flotation machine such as feed slurry flowrate (l/h); air flowrate (l/h); feed nozzles size (mm) and froth height (mm). Thus, the optimal have been selected for the flotation test programme. Furthermore, in order to evaluate the effect of the reduced froth surface area, using a conical froth crowder (booster cone) on the concentrate mass pull, grade and recovery, a series of flotation experiments with or without central froth crowder have been performed. The obtained results show the possibilities for PNEUFLOT flotation technology implementation in the copper flotation plants.

Keywords: Pneuflot, copper-porphyry ore, flotation, parameters

ВЪЗМОЖНОСТИ ЗА ПРИЛОЖЕНИЕ НА ФЛОТАЦИОННА МАШИНА PNEUFLOT ПРИ ПРЕРАБОТКАТА НА МЕДНО-ПОРФИРНИ РУДИ

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РЕЗЮМЕ. В представеното изследване бяха анализирани възможностите за флотация с предварителен контакт на Cu и Mo от медно-порфирни руди. Лабораторните изследвания бяха проведени с пневматична флотационна машина PNEUFLOT® (MBE Coal & Minerals Technology). Основно внимание беше обърнато на променливите параметри на флотационната машина, като дебит на пулпа (l/h); дебит на въздуха (l/h); размер на захранващите дюзи (mm) и височината на пения слой (mm). За флотационните тестове бяха определени и избрани оптималните технически параметри на флотационната машина. Проведени са серия от флотационни тестове с оптимизирани технически параметри на флотационната машина PNEUFLOT, като е контролирана площта на общата повърхност на пенната формация на флотационната машина. Общата повърхност на пенната формация се регулира чрез поставянето на конус в горната част на флотационната клетка, което дава възможност за намаляването й. Проведени са два вида флотационни тестове - със и без конус. Получените резултати от извършените флотационни изследвания, показват възможностите за внедряване на флотационна машина PNEUFLOT в медно преработвателните комплекси.

Ключови думи: Pneuflot, медно-порфирна руда, флотация, параметри

Introductıon

Flotation is one of the most important physico-chemical separation processes, used largely in mineral separation operations. In the last three decades the use of pneumatic flotation machines (most common pneumatic flotation columns - "short columns" - refer to other non-mechanical flotation cells, variously referred to as novel columns, pneumatic cells and high intensity cells) became wide-spread throughout the mineral processing industry of metallic, non-metallic ores, coal, etc. (Harbort, Clarke, 2016). Pneumatic flotation has developed very substantially since the 1920's, up to the new designs proposed by Dr. Rainer Imhof in Germany.

The pneumatic pre-contact flotation machines are representatives of a new generation of flotation machines with a number of design features that improve the flotation process. The mixing of the solid and gas phases in an aqueous medium is carried out in advance, outside the volume of the flotation cell, in heterogeneous devices designated by the various manufacturers, such as aeration devices, mixing chambers, and others. The elementary flotation act (attachment of hydrophilic solid particles to air bubbles) occurs in these devices. Pre-contact flotation machines do not have an impeller system which means there is no wear and tear in the stator-rotor system. Another important feature is the ability to create finer air bubbles and lower air consumption than conventional pneumo-mechanical machines, resulting in flotation of fine products and production of high-quality concentrates.

Since 2009 MBE Coal and Minerals Technology GmbH has been manufacturing and developing the PNEUFLOT flotation machine. A brief description of PNEUFLOT operating principles is presented below.

The flotation pulp is first directed to a single aerating unit arranged in the vertical pipe above the flotation cell. The aerator (self-aerated) is installed in the vertical feed pipe. Following aeration, the pulp flows through the central pipe to the slurry distributor ring located at the bottom of the cell where it is vertically deflected upward through high wear resistant ceramic nozzles. The air bubbles covered with hydrophobic particles ascend to the upper cell area and form a froth layer on the surface which flows off into a froth launder surrounding the cell like a ring. Particles not clinging to air bubbles are discharged with the pulp from the bottommost point of the cell. The pulp level is kept constant either by a level probe which actuates a valve controlling the discharge or by a device known as a "gooseneck discharge". The necessary flow rate and pressure are delivered by the appropriate slurry feed pump. The pulp distributor injects the aerated pulp in an upward motion into the flotation vessel. The cell is only responsible for separating the remaining pulp from the froth formed by the loaded bubbles. (Flotation Technology Brochure, PNEUFLOT®, 2011).

The first PNEUFLOT pneumatic flotation plant was put into operation in Pennsylvania in 1987. The installation, owned by Pittstone Coal Co., is for coal flotation, and since then PNEUFLOT has been widely applied in the processing of coal and coal slimes, industrial minerals, iron minerals, and non-ferrous metals such as copper, lead, nickel, and zinc and precious metals - platinum, gold, silver and etc. A schematic view of the PNEUFLOT flotation machine is shown in Figure 1.

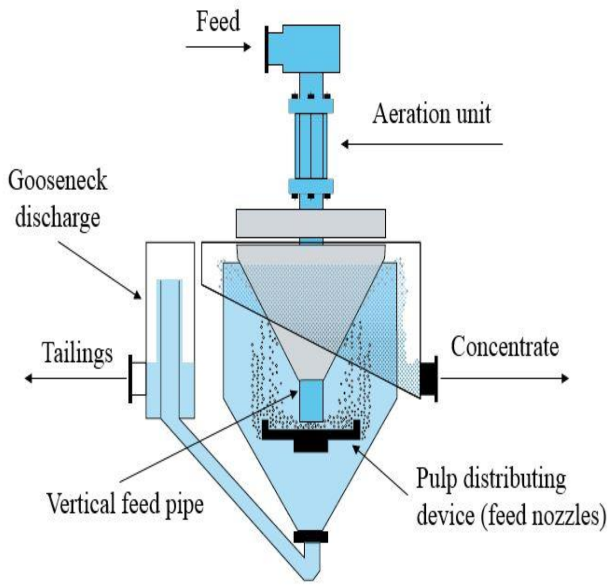

Fig. 1. Schematic view of the PNEUFLOT flotation cell (MBE Coal & Minerals Technology GMBH)

The aim of this study was to evaluate the optimal operating parameters of PNEUFLOT flotation machine and to investigate the influences of these operation variables on the recovery of Cu and Mo during copper-porphyry ore flotation.

Materials and Methods

A series of flotation tests were conducted on the laboratory PNEUFLOT (Figure 2) flotation machine in order to provide data regarding the following operating parameters:

- Optimal feed slurry flowrate (l/h);
- Optimal air flowrate (l/h);
- Optimal feed nozzles size (mm);
- Optimal froth height (mm).

The feed slurry for the laboratory flotation tests was collected from the hydrocyclone overflow stream, which enters the Cu rougher flotation circuit. The assays for the flotation programme comprised Cu, Mo, SiO_2, Fe, S.

Fig. 2. Laboratory PNEUFLOT flotation cell

Investigation of feed slurry flowrate (l/h)

In order to evaluate the optimal feed slurry flowrate (l/h), a series of flotation experiments within the range of 210 to 400 l/h have been conducted. The operating parameters during the flotation experiments are presented in Table 1.

Table 1. *Batch laboratory tests operating conditions*

Parameters	Value
Feed slurry (l)	50
Solids concentration (%w/w)	30
Residual CaO concentration (mg/l)	650
Flotation time (min.)	9
Air flowrate (l/h)	400
Feed nozzles size (mm)	2.70
Froth height (mm)	60

Investigation of air flowrate (l/h)

In order to evaluate the optimal air flowrate (l/h), a series of flotation experiments within the range of 150 to 800 l/h have been conducted. The operating parameters during the flotation experiments are presented in Table 2.

Table 2. *Batch laboratory tests operating conditions*

Parameters	Value
Feed slurry (l)	50
Solids concentration (%w/w)	30
Residual CaO concentration (mg/l)	650
Flotation time (min.)	9
Feed slurry flowrate (l/h)	350
Feed nozzles opening size (mm)	2.70
Froth height (mm)	70

Investigation of feed nozzles size (mm)

In order to evaluate the optimal opening size of the feed nozzles (mm), a series of flotation experiments with the available nozzle: 2.7, 3.00 and 3.30 mm have been conducted. The operating parameters during the flotation experiments are presented in Table 3.

Table 3. *Batch laboratory tests operating conditions*

Parameters	Value
Feed slurry (l)	50
Solids concentration (%w/w)	30
Residual CaO concentration (mg/l)	650
Flotation time (min.)	9
Feed slurry flowrate (l/h)	350
Air flowrate (l/h)	300
Froth height (mm)	70

Investigation of froth height (mm)

In order to evaluate the optimal froth height (mm), a series of flotation experiments within the range of 40 to 100 mm have been conducted. The operating parameters during the flotation experiments are presented in Table 4.

Table 4. *Batch laboratory tests operating conditions*

Parameters	Value
Feed slurry (l)	50
Solids concentration (%w/w)	30
Residual CaO concentration (mg/l)	650
Flotation time (min.)	9
Feed slurry flowrate (l/h)	350
Air flowrate (l/h)	400
Feed nozzles opening size	2.7

According to Wang et al. (2015) the recovery of gangue particles is greatly influenced by froth heights. As mentioned by Szatkowski (1987) and Wang et al. (2015) a decrease in recovery of gangue minerals occurs when there is an increase in froth height. This is because the increase in froth height extends the froth residence time and promotes drainage of particles per unit mass of water in the froth phase back to the pulp phase.

Investigation of froth surface area (with/without central froth crowder)

The function of the crowder is to decrease the cross sectional area at the top of the froth to improve the froth removal dynamics in the flotation cell. The walls of a crowder provide a surface to direct froth toward the overflow launder (Cole et al., 2011).

The formation of the froth surface area is regulated by the placement of a cone in the upper part of the flotation cell. In order to evaluate the influence of the reduced froth surface area on the recovery and kinetics efficiencies, a series of flotation experiments with and without central froth crowder have been performed.

The following section of the article will discuss the obtained results from the flotation experiment with the investigated operating parameters - feed slurry flowrate, air flowrate, feed nozzles size, froth height and froth surface area.

Results and discussions

Based on the results from the flotation experiments, the optimal operating parameters of the PNEUFLOT flotation machine have been determined (Table 5).

Table 5. *Selected optimal PNEUFLOT machine operating parameters*

Operating parameters	Value
Feed slurry flowrate	350 l/h
Air flowrate	300 l/h
Feed nozzles opening size	2.70 mm
Froth height	80.00 mm

Selected results from the flotation experiments regarding the examination of the optimal operating parameters of the PNEUFLOT flotation machine are presented below.

Investigation of feed slurry flowrate (l/h)

Throughout the flotation tests, the best Cu & Mo grade and recovery were achieved when the feed slurry flowrate was set to 350 l/h. The flotation test results are presented in Table 6-7.

Table 6. *Grade results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Grade, %				
		SiO_2	Cu	Mo, g/t	Fe	S
Conc	40.82	19.91	6.35	329.93	31.75	36.03
Tail	59.18	22.64	1.57	180.91	31.84	37.16
Feed	100.0	21.52	3.52	241.74	31.8	36.7

Table 7. *Recovery results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Recovery, %				
		SiO_2	Cu	Mo	Fe	S
Conc	40.82	37.75	73.59	55.71	40.75	40.08
Tail	59.18	62.25	26.41	44.29	59.25	59.92
Feed	100	100	100	100	100	100

Investigation of air flowrate (l/h)

In the course of the experiments higher Cu & Mo grade and recovery were achieved when the air flowrate was set to 300 l/h. The flotation test results are presented in Table 8-9.

Table 8. *Grade results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Grade, %				
		SiO_2	Cu	Mo, g/t	Fe	S
Conc	36.14	16.4	6.87	5108.2	31.40	40.08
Tail	63.86	21.73	1.86	1905	30.50	38.97
Feed	100	19.82	3.67	3062.55	30.83	39.37

Table 9. *Recovery results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Recovery, %				
		SiO_2	Cu	Mo	Fe	S
Conc	36.14	29.98	67.69	60.28	36.81	36.79
Tail	63.86	70.02	32.31	39.72	63.19	63.21
Feed	100	100	100	100	100	100

Investigation of feed nozzles size (mm)

During the flotation tests with variable feed nozzle the optimum Cu & Mo grade and recovery were achieved with 2.7 mm opening size. The flotation test results are presented in Tables 10-11.

Table 10. *Grade results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Grade, %				
		SiO_2	Cu	Mo, g/t	Fe	S
Conc	32.48	15.44	9.15	386.22	31.49	38.30
Tail	67.52	29.48	1.54	215.38	31.76	35.66
Feed	100	24.92	4.01	270.86	31.67	36.52

Table 11. *Recovery results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Recovery, %				
		SiO_2	Cu	Mo	Fe	S
Conc	32.48	20.13	74.03	46.31	32.29	34.06
Tail	67.52	79.87	25.97	53.69	67.71	65.94
Feed	100	100	100	100	100	100

Investigation of froth height (mm)

Higher values of Cu & Mo grade and recovery while maintaining the froth height around 80 mm were achieved during the flotation experiments. The flotation test results are presented in Table 12-13.

Table 12. *Grade results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Grade, %				
		SiO_2	Cu	Mo, g/t	Fe	S
Conc	26.96	12.43	7.46	4230.52	33.38	41.38
Tail	73.04	22.08	2.36	2391	29.95	39.84
Feed	100	19.48	3.73	2887.18	30.87	40.26

Table 13. *Recovery results of flotation test for optimal feed slurry flowrate*

Products	Mass pull, %	Recovery, %				
		SiO_2	Cu	Mo	Fe	S
Conc	26.96	17.20	53.83	39.50	29.15	27.71
Tail	73.04	82.80	46.17	60.50	70.85	72.29
Feed	100	100	100	100	100	100

Investigation of froth surface area (with/without central froth crowder)

Tables 14, 15, 16 and 17 below, presents the results from the flotation experiments conducted with and without using a conical froth crowder, attached on the top of the flotation cell.

Table 14. *Grade results of flotation test with a central froth crowder*

Products	Mass pull, %	Grade, %				
		Cu	Mo, g/t	Fe	S	SiO_2
Ro Conc 1 (2`)	10.63	10.46	1939	28.57	36.08	19.43
Ro Conc 2 (5`)	9.07	8.29	2907	28.43	33.99	21.16
Ro Conc 3 (7`)	7.46	6.68	3784	24.58	3.18	27
Ro Conc 4 (9`)	9.47	4.65	4483	24.67	31.86	29.19
Ro Conc	36.64	7.65	3212.04	26.71	27.77	23.92
Scavenger Conc (18`)	20.35	4.54	5153	21.63	30.83	31.94
Tail	43.01	0.949	806	29.38	36.9	23.86
Feed	100.0	4.14	2572.37	26.83	32.32	25.53

Table 15. *Recovery results of flotation test with a central froth crowder*

Products	Mass pull, %	Recovery, %				
		Cu	Mo	Fe	S	SiO_2
Ro Conc 1 (2`)	10.63	26.90	8.02	11.33	11.87	8.09
Ro Conc 2 (5`)	9.07	18.19	10.25	9.61	9.54	7.52
Ro Conc 3 (7`)	7.46	12.06	10.98	6.84	0.73	7.89
Ro Conc 4 (9`)	9.47	10.65	16.50	8.71	9.34	10.83
Ro Conc	36.64	67.79	45.75	36.49	31.48	34.34
Scavenger Conc (18`)	20.35	22.34	40.77	16.41	19.42	25.47
Tail	43.01	9.87	13.47	47.10	49.10	40.20
Feed	100	100	100	100	100	100

Table 16. *Grade results of flotation test without using a central froth crowder*

Products	Mass pull, %	Grade, %				
		Cu	Mo, g/t	Fe	S	SiO_2
Ro Conc 1 (2`)	12.33	10.23	1696	30.67	37.57	15.73
Ro Conc 2 (5`)	15.07	6.74	3302	28.06	36.31	21.22
Ro Conc 3 (7`)	9.61	4.56	4304	26.31	34.97	26.05
Ro Conc 4 (9`)	8.78	3.15	4245	25.85	33.26	23.61
Ro Conc	45.79	6.53	3260.59	27.97	35.78	21.21
Scavenger Conc (18`)	17.74	3.289	3060	27.88	36.98	23.49
Tail	36.47	0.979	830	27.87	33.7	27.26
Feed	100.0	3.93	2338.53	27.92	35.24	23.82

Table 17. *Recovery results of flotation test without using a central froth crowder*

Products	Mass pull, %	Recovery, %				
		Cu	Mo	Fe	S	SiO_2
Ro Conc 1 (2`)	12.33	32.08	8.94	13.55	13.15	8.14
Ro Conc 2 (5`)	15.07	25.83	21.28	15.14	15.53	13.42
Ro Conc 3 (7`)	9.61	11.14	17.68	9.05	9.54	10.51
Ro Conc 4 (9`)	8.78	7.03	15.94	8.13	8.29	8.70
Ro Conc	45.79	76.08	63.84	45.88	46.50	40.77
Scavenger Conc (18`)	17.74	14.84	23.21	17.72	18.62	17.49
Tail	36.47	9.08	12.94	36.41	34.88	41.73
Feed	100	100	100	100	100	100

The results show that when using a froth crowder, due to the reduced froth area size, a lower weight pulls (36.64%) was achieved, but with higher Cu grade (7.65%) and nearly the same Mo content (3212 g/t) compared to the experiment conducted without froth crowder. The overall Cu recovery (rougher + cleaner) from both flotation tests reached approximately 90%. Noticeable difference in the Mo grade of the scavenger concentrates from both experiments was found, as in the experiment with central froth crowder the scavenger concentrate assaying 5153 g/t compared to 3060 g/t, without using a central froth crowder. A possible explanation for this might be that during the flotation test with central froth crowder the height of the froth was increased which led to longer froth retention time which in turn contributed to decrease in the recovery of gangue minerals by entrainment. According to Zheng et al. (2006) with an increase in froth retention time, more water and entrained particles (mainly gangue minerals) are expected to drain out of the froth phase, leading to improved concentrate grade.

Conclusions

The results presented in this paper clearly show the applicability of PNEUFLOT flotation technology for Cu and Mo recovery in the flotation of copper-porphyry ores. The Cu and Mo recoveries in the rougher flotation concentrates during the investigation of optimal parameters were acceptable, ranging from 67 to 76% for Cu and from 39 to 60 % for Mo. Higher molybdenum grades in the scavenger concentrate reaching up to 5153 g/t were accomplished. It seems possible that these results are due to the PNEUFLOT flotation cell hydrodynamic creating a suitable condition for effective separation (higher selectivity) of the sulphide Cu and Mo minerals from gangue (SiO_2, clays, etc.) components. Thanks to the very small area where the air injection to slurry is conducted before entering the separation vessel, the flotation process needs less time compared to other flotation technologies. It could be concluded that the PNEUFLOT flotation machine is an effective solution for flotation process plants.

References

Cole, K. E., P. R. Brito-Parada, S. J. Neethling, J. J. Cilliers. 2011. *A model of froth motion to test flotation cell crowder designs – experimental validation with overflowing 2D foam.* Rio Tinto Centre for Advanced Mineral Recovery, Froth and Foam Research Group, Department of Earth Science and Engineering, Imperial College London, South ensington Campus, London, United Kingdom, 2 p.

Harbort, G., D. Clarke. 2006. Fluctuations in the popularity and usage of fotation columns – An overview. – *Mineral Engineering*, *100*, 17–30.

MBE Coal & Minerals Technology GMBH. 2011. *Flotation Technology Brochure. PNEUFLOT®*, Cologne, Germany.

Szatkowski, M. 1987. *Factors influencing behavior of flotation froth. – Ins. Min. Metall. Trans., Sect. C. Miner. Process. Extract. Metall., 96*, 115–122.

Wang, L., Y. Peng, K. Runge, D. Bradshaw. 2015. A review of entrainment: Mechanisms, contributing factors and modeling in flotation. – *Minerals Engineering, 70*, 77–91.

Zheng, X., N. W. Johnson, J. P. Franzidis. 2006. Modelling of entrainment in industrial flotation cells: Water recovery and degree of entrainment. – *Minerals Engineering*, *19*, 1191–1203.