Physicochem. Probl. Miner. Process., 54(1), 2018, 174-181

www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems of Mineral Processing

ISSN 1643-1049

Received November 23, 2016; reviewed; accepted August 29, 2017

Comparison of Jameson cell and jet diffuser flotation column

Kemal Bilir [1], Ali Ucar [2], Oktay Sahbaz [2], Hakan Gursoy [1], Bahri Oteyaka [1]

[1] Department of Mining Engineering, Eskisehir Osmangazi University, Eskisehir, Turkey

[2] Department of Mining Engineering, Dumlupinar University, Kutahya, Turkey

Corresponding author: oktay.sahbaz@dpu.edu.tr (Oktay Sahbaz)

Abstract: A Jet Diffuser Flotation Column (JDFC) is a newly designed flotation device which resembles the Jameson cell (JFC) in terms of operational principles, but it has an important difference regarding to the structural characteristics in the downcomer. The main difference of JDFC is the diffuser type of downcomer which has been designed using the hydrodynamic consideration and fluid mechanics principles. The aim of the design was to increase the device efficiency for coarse particle flotation. Therefore, the turbulence occurring at the end of the downcomer was reduced, and the detachment probability of the coarse particle decreased. In addition, a homogenous and stable foam zone in the cell was obtained. According to the experimental results carried out in a pilot scale showed that not only higher flotation performance in comparison to the Jameson cell was obtained specifically for the coarse particles but also the quiescent froth layer was acquired under the given conditions. In these experiments, a vertical pipe of JDFC having an inlet diameter of 60 mm and outlet diameters of 115, 125 and 135 mm was used with the separation tank with the diameter of 390 mm. By using the data, the pilot scale JDFC with the 4100 mm vertical pipe integrated with the separation tank was produced, and the flotation tests were carried out by using a talc ore. Finally, the talc recovery of 90% was obtained using the JDFC for the particle size of 350 μm.

Keywords: *Jet diffuser flotation column, flotation, Jameson Cell, talc*

1. Introduction

Flotation is a physicochemical process used in order to separate hydrophobic minerals from hydrophilic ones. Flotation is generally applied for fine-grained and low-grade ores due to its higher performance against physical methods. The performance of flotation methods depends on many variables including particle size, bubble size, chemicals (reagents) used and their amounts, the hydrodynamic behavior of the system, characteristics of the equipment etc. (Drzymala, 1994; Klimpel, 1995; Fuerstenau, 1999; Kawatra, 2015). A flotation process is quite sensitive to levels of these variables especially the particle size, turbulence of the system, and the bubble diameter.

The flotation performance decreases by coarse or fine feeding in conventional flotation cells (Trahar, 1981). The main reason for this performance decrease is a low probability of bubble-particle collision for fine particles and unstable bubble-particle aggregate for coarse particles (Schulze, 1993; Kowalczuk et al., 2014). Therefore, researchers have performed many studies to solve the mentioned problems, and provided new flowsheets, circuits, and flotation devices (Dobby and Finch, 1986; Jameson, 1988; Sahbaz, 2010; Oteyaka et al., 2014 a,b). Some of the devices invented for flotation are air-sparged hydrocyclone (Miller, 1981), centrifugal flotation cell (Ding et al., 1999; Guo, 2002), contact cell (Amelunxen, 1993), centrifloat (Drummond, 1994), Jameson cell (Jameson, 1988), and others (Finch, 1995; Cheng and Liu, 2015). Most of them have been designed at the laboratory scale, whereas the Jameson cell has many industrial applications worldwide.

The Jameson cell has been applied to more than 300 mineral processing plants due to the compact design and fine bubble generation resulting in a better bubble-particle collision. Therefore, the device has been used specifically for fine particle flotation. However, in some plants, coarser feeding is a

http://dx.doi.org/10.5277/ppmp1836

necessity due to the operational reason, and researchers have investigated the increase of the cell performance for coarse particles (Cowburn et al., 2006; Sahbaz et al., 2013).

Some authors have investigated the coarse particle flotation performance of the Jameson cell, and they have revealed main reasons for the performance decrease (Cowburn et al., 2006; Sahbaz et al., 2012, 2013; Oteyaka et al., 2014 a, b). In the light of these findings, a new device (Oteyaka et al., 2014 a, b) similar to the Jameson cell in terms of operational principles has been improved for the coarse particle flotation. In this study, the design variables of a new flotation device called as a Jet Diffuser Flotation Column (JDFC), and its application for talc was investigated.

2. Jet diffuser flotation column

Industrial application of the Jameson cell for fine particles is common worldwide, and the cell has a very high flotation rate. Therefore, many researchers have focused on the performance of the cell for coarse particle flotation (Cowburn et al, 2006; Sahbaz, 2010; Sahbaz et al., 2013). Sahbaz (2010) and Sahbaz et al. (2012 and 2013) determined the main turbulent regions in the Jameson cell to figure out the main region causing the coarse particle detachment.

There are two main turbulent regions in the Jameson cell (Sahbaz, 2010; Sahbaz et al., 2012; Sahbaz et al., 2013). The first turbulent region is at the top of the downcomer which is called a mixing zone (Evans et al., 1995). This region is responsible for fine bubble generation, and the primary contacting zone of bubble and particle. The second turbulent region in the Jameson cell occurs at the outlet of the downcomer due to the pulp flow into the separation tank from the downcomer (Sahbaz, 2010; Sahbaz et al., 2012; Sahbaz et al., 2013). This region, which can be called a critical region, is possibly the main reason for bubble-coarse particle instability and recovery decrease. Therefore, it is very important for quantitative determination of the magnitude of turbulence in this critical region.

Sahbaz (2010) and Sahbaz et al. (2012 and 2013) improved a mathematical model (Eq. 1) for the quantitative determination of turbulence in the critical region. Derivation of the equation was explained in details in the study of Sahbaz et al. (2013):

$$G_T = \sqrt{\frac{\pi d_D^2 \rho_l (1-\varepsilon) U^3 + \rho_b d_b^2 U_b^3 N_b}{8 V_{CR} \mu_l}} \tag{1}$$

where:

G_T : velocity gradient at the outlet of downcomer, dm^3/s
d_D : downcomer diameter, m
ρ_l : density of liquid, kg/m^3
ε : hold-up, %
U : pulp velocity, m/s
ρ_b : density of bubble, kg/m^3
d_b : bubble diameter, m
U_b : bubble velocity, m/s
N_b : the number of bubble passing in the cross-section of downcomer in a unit time
V_{CR} : volume of liquid exposed to power generated by air and liquid phases, m^3
μ_l : viscosity of the liquid, kg/ms.

According to Eq. 1, the turbulence in the critical zone of laboratory scale Jameson cell was computed as a 700-710 s^{-1}. The model informs which variables are affective on turbulence in the critical region. According to the model, turbulence decreases with the increase in the downcomer diameter. Other variables, except for the downcomer diameter, must be constant in terms of operational principles of the Jameson cell. When the downcomer diameter is thought to be constant for the given conditions to obtain optimum results, it seems that there is only one solution which is the increase of outlet diameter of the downcomer as a diffuser. Thus, a decrease in turbulence could be obtained at the end of the downcomer due to reduction in the pulp flow velocity (Eq. 1).

In the light of the explanation above, a new device was designed (Oteyaka et al., 2014 a, b). Sahbaz (2010) designed a new equipment considering diffusers and their effect on turbulence in any discharge point. The most suitable diffuser geometry to provide optimum flow from the downcomer to separation tank was determined using the fluid mechanics principles. The optimum flow means uniform flow causing the less turbulence (Fig. 1b). The diffuser angle, length, and width was determined by the use of Figs. 1 and 2 as x, y, and 115 mm, respectively.

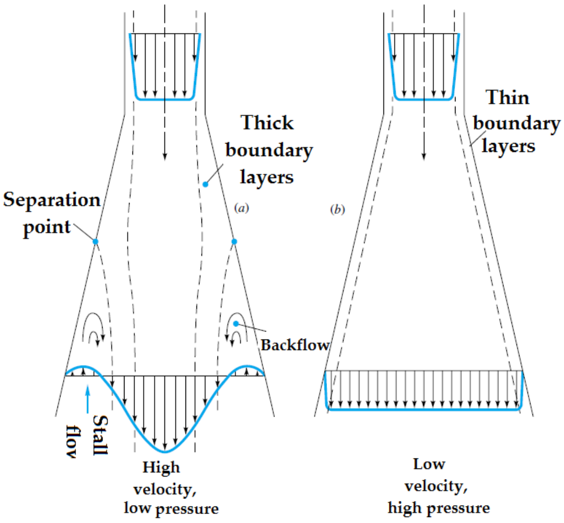

Fig. 1. Diffuser flow types: a) irregular b) regular flows (White, 2005)

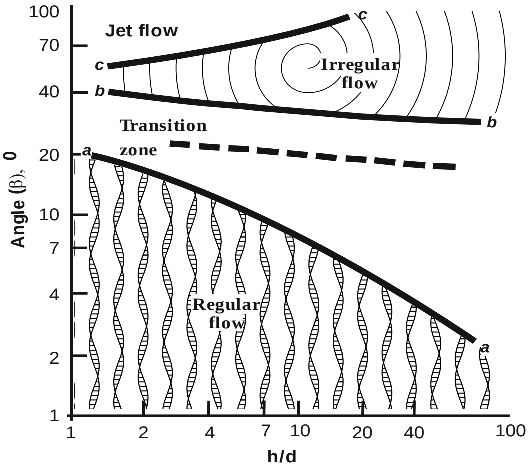

Fig. 2. Stability diagram (Fox and Kline, 1962)

The Jet Diffuser Flotation Column (JDFC) was constructed at Eskisehir Osmangazi University Mineral Processing Laboratory at a pilot scale (Table 1 and Fig. 3). The diffuser part of the cell is removable to change it as the classical downcomer.

According to the observations obtained in the two-phase flow, plunging length of the discharged slurry was around 85 mm for the Jameson cell, while it was around 15 mm for the JDFC. This observation showed that the turbulence in the JDFC was lower than in the Jameson cell. A series of experiments were carried out to determine the performance of the JDFC.

Table 1. JDFC size

Downcomer	Diameter	60 mm
	Length	4100 mm
Separation tank	Diameter	390 mm
	Length	1300 mm
Nozzle	Diameter	9.5 mm
Diffuser	Outlet Diameter	115 mm

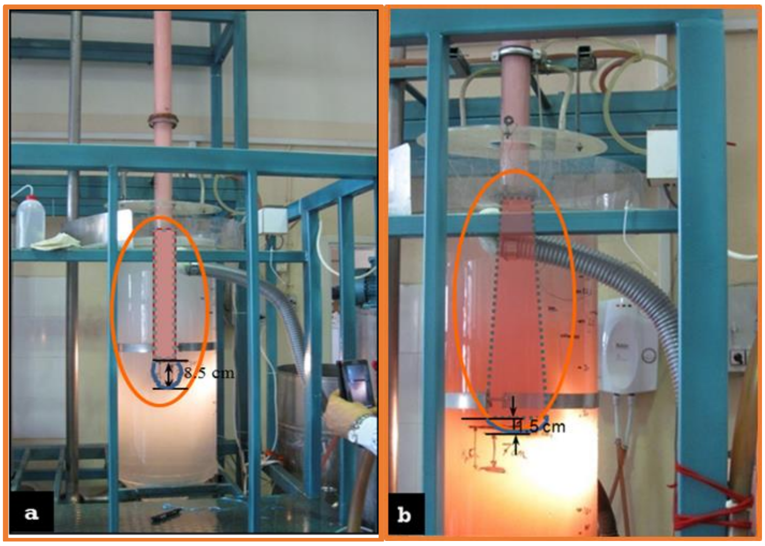

Fig. 3. (a) Jameson cell (b) Jet Diffuser Flotation Column

2. Experimental

In the experimental study, a naturally hydrophobic talc sample with a purity of 97.6% (based on MgO) was used. The operational variables of the JDFC setup are given in Table 2. All flows were controlled with the flowmeters and gauges.

The experiments were carried out under conditions of negative and positive bias factors, which are very effective operational variables for recovery in the Jameson cell. The bias factor is defined by the fraction of the wash water flowing downward and reporting to tailing stream (Sahbaz et al., 2008). It is estimated by using the expression given by Mohanty and Honaker (1999):

$$\textit{Bias factor} = (Q_W - Q_F)/Q_{WW}, \tag{2}$$

where Q_W, Q_F, and Q_{WW} are the flow rates of tailing (65 dm^3/min), feed (62.4 dm^3/min), and wash water (7 dm^3/min), respectively.

Table 2. Variables and their level values used in JDFC

Variables	Value
Nozzle diameter, mm	9.5
Hold-up (ε), %	51.4 (ε= 0,322y^3 – 1,07y^2 + 1,29y, y=APR, Harbort et al, 2002)
Particle size, mm	-0.400 + 0.300 (0.350), -0.300 + 0.212 (0.256), -0.212 + 0.106 (0.159) and -0.106 + 0.020 (0.063)
Bubble size, mm	0.5 – 1.5
Solid ratio, %	2.5
Flotation time, min	10 (bypass system)
Frother (AF65), ppm	20
Pulp flow rate, dm^3/min	62.4
Tailing flow rate, dm^3/min	65 (in positive bias)
Tailing flow rate, dm^3/min	54 (in negative bias)
Air flow rate, dm^3/min	50.3
Air-to-pulp ratio (APR)	0.81
Superficial gas velocity, cm/s	0.7
Downcomer plunging, mm	700
Feeding pressure, kPa	110

All operational conditions were kept the same for both Jameson cell and the JDFC. The representative talc samples were prepared for each test and fed to the devices with the pressure of 110 kPa. In the experiments with positive bias factor, 65 dm^3/min of tailing were taken from the devices, and the washing water was kept as 7 dm^3/min to obtain the bias factor as +0.2. On the other hand, in the negative bias factor experiments, the washing water was not used, while the tailing rate was 54 dm3/min in the fixed feed rate which was 62.4 dm^3/min as seen in Table 2.

Additional series of experiments were also carried out to show the effect of outlet diameter of the diffusers. For that reason, the diffusers with the diameter of 115, 125, and 135 mm were used in these experiments.

3. Results and discussion

The experimental study was carried out by the use of JDFC and the Jameson cell in negative and positive bias factors to check whether the JDFC had advantages over the Jameson cell in terms of coarse particle flotation. All experiments were repeated two or three times, and the average of these experimental results was used as the final results. Figures 4 and 5 show the results of the experimental study carried out in positive and negative bias factors, respectively.

Under all conditions of positive and negative bias factors, mineral recovery started to decrease with the coarser feeding in both devices (Figs. 4 and 5). Under the positive bias condition, the recovery decreased from 85% to 66% in the Jameson cell and from 85% to 80% in the JDFC when the feed size was changed to 350 µm from 63 µm (Fig. 4). The recovery of talc in the JDFC was approximately 93% for the particle size of 159 µm. Approximately 15% increase was obtained for the coarse particle by the use of the JDFC compared to the results of Jameson cell.

Figure 5 shows the flotation results for both the JDFC and JFC under negative bias (0.12 cm/s) conditions. According to Fig. 5, the recovery results were nearly the same in both devices for the finest particle size, while 20% increase was obtained by the use of JDFC for the coarsest size. The recovery was approximately 98% for the particle size of 159 µm. The JDFC had the ability to recover more talc mineral than the Jameson cell under both negative and positive bias conditions (Figs. 4 and 5). The increase of the outlet diameter of the diffuser connected to the tip of the downcomer provided the reduction of the turbulence at the end of the downcomer, and therefore the detachment of bubble-particle especially for the coarse particles decreased hydrodynamically. Thus, the recovery loss in the Jameson cell for the coarser feeding decreased by this new modification. Sahbaz et al. (2012) claimed that the turbulence decrease was obtained by the increase of downcomer diameter that could provide better aggregate stability for the coarse particles. This hypothesis has been confirmed by this finding as well.

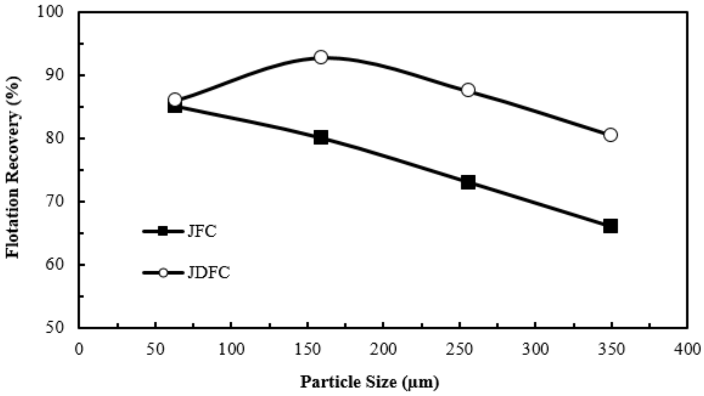

Fig. 4. Comparison of talc recovery with positive bias factor by using JFC (Oteyaka et al., 2014a) and JDFC

Figure 6 shows the results of talc recovery by using the JDFC under both negative and bias conditions. According to the results, the typical *U*-shaped curve was obtained, and the highest possible recovery was achieved for the particle size of 159 µm. The dramatic decrease was observed for both coarser and finer sizes due to the low stability and collision probability, respectively. This finding confirms the results obtained by some previous studies carried out by Scheludko et al. (1976), Schulze (1993), Drzymala (1994), and Nguyen et al. (1997). Figure 6 also states that the higher recovery for talc flotation was obtained under the negative bias condition (without froth zone), and this increase was specifically higher for the coarse particles. Under the positive bias conditions, there was a froth zone, which was an obstacle to the bubble-particle aggregates. Bubble-coarse particle aggregates cannot levitate up to the top of the cell due to this thick zone and start to detach resulting the recovery loss (Oteyaka, 1993; Oteyaka and Soto, 1995). Bubble-fine particle aggregates are more stable than the coarse one due to the less mass, and these aggregates are affected less specifically under the positive bias condition. Therefore, the recovery of the fine particle was higher than that of the coarse particle

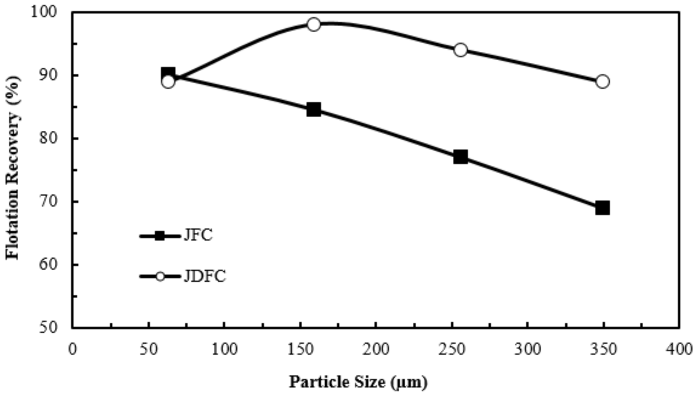

Fig. 5. Comparison of talc recovery with negative bias by using JFC (Oteyaka et al., 2014a) and JDFC

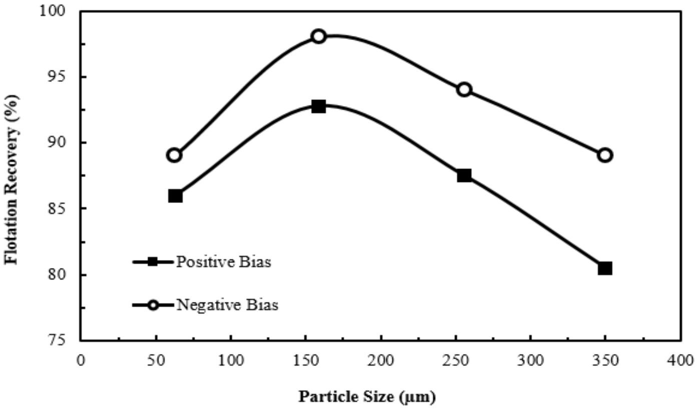

Fig. 6. Talc recovery in JDFC for positive and negative bias

To determine the effect of diffuser diameter on the flotation recovery, a series of experiments were carried out by using three different the JDFC with the diffuser diameter of 115, 125, and 135 mm. Figure 7 shows the results of the effect of diffuser diameter on the flotation recovery of talc. According to Fig. 7, the greater the diffuser outlet diameter, the higher recovery for the coarse particle. On the other hand, the recovery was higher for fine particles (63 µm) when the diffuser diameter was similar to the classical Jameson cell.

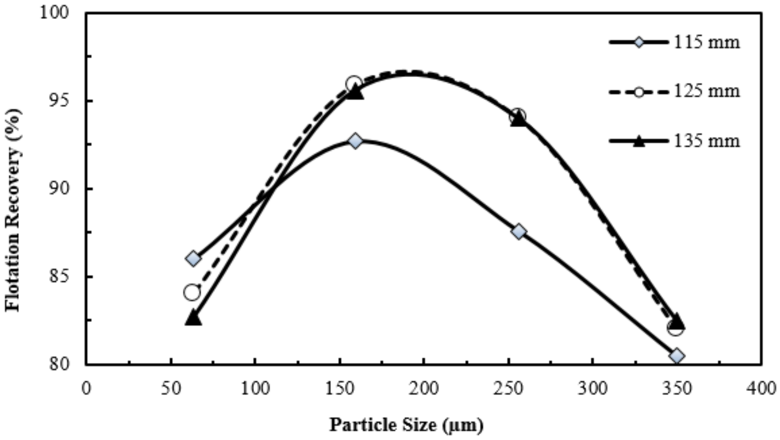

Fig. 7. Effect of diffuser diameter on flotation recovery

The main reason for the recovery increase for the coarse particles was related to turbulence decrease due to the diffuser type geometry of downcomer of the JDFC. The increment of the outlet of the downcomer provided the velocity decrease for the pulp which were discharging from the downcomer to the separation tank. Thus, the total turbulence reduced due to the velocity decrease, and the probability of detachment also decreased

4. Conclusions

Factors affecting the recovery decrease for the coarse particles were determined by using the previous studies on the Jameson cell, and a modified cell called as a Jet Diffuser Flotation Column (JDFC) was designed to provide better flotation recovery. In this study, a pilot scale JDFC was designed having the length, inlet, and outlet diameter of 500 mm, 60 mm, and 115 mm, respectively. This study showed that the turbulence in the separation tank of the cell decreased, and uniform rising of bubble-particle aggregates was provided.

Less fluctuation was obtained in the separation tank by increasing the outlet diameter of the downcomer. Additionally, the better aggregate stability was obtained. The JDFC had a better flotation performance for the coarse particles in comparison to the Jameson cell. The performance of both devices was better under the negative bias condition due to the lack of froth zone.

Under the negative bias condition, coarse talc particles (350 µm) were obtained with the recovery of 90% in the JDFC, while this value was nearly 70% in the Jameson cell flotation. The best recovery of JDFC was obtained in the particle size range of -212 +106 µm in positive and negative bias conditions. The Jameson cell had a high performance for the fine particles in the negative bias condition

Acknowledgements

Authors acknowledge the Eskisehir Osmangazi University Scientific Research Project Unit for providing financial support. The authors are also thankful to Prof. Dr. Graeme J. Jameson for his help for designing the laboratory scale Jameson cell which is the basic device and source of inspiration of our new design.

References

AMELUNXEN R.L., 1993. *The contact cell-A future generation of flotation machines*. E&MJ-Engineering and Mining Journal, 194(4), 36-37.

CHENG G., LIU J.T., 2015. *Development of column flotation technology*. Journal of Chemical and Pharmaceutical Research, 7(2), 540-549.

COWBURN J., HARBORT G., MANLAPIG E., POKRAJCIC Z., 2006. *Improving the recovery of coarse coal particles in Jameson cel*. Minerals Engineering, 19, 609–618.

DING J., YEN W.T., PINDRED A.R., 1999. *Centrifugal flotation cell with rotating feed*. U.S. Patent No 5,914,034.

DOBBY G.S., FINCH J.A., 1986. *Flotation column scale-up and modelling*. CIM Bulletin, No: 889, May, 89-96.

DRUMMOND R., GRAHAM J., SCHNEIDER J., DUCZMAL T., 1994. *Evaluation of plant scale centrifloat flotation cell at BHP Australia Coal Limited, Goonyella Coal Preparation Plant*. Coal Preparation, 94.

DRZYMALA J., 1994. *Hydrophobicity and collectorless flotation of inorganic materials.* Advances in Colloids and Interface Science, 50, 143-185.

DRZYMALA J., 1994. *Characterization of materials by Hallimond tube flotation, Part 2. Maximum size of floating particles and contact angle*. International Journal of Mineral Processing, 42, 153–167.

EVANS G.M., ATKINSON B., JAMESON G.J., 1995. *The Jameson cell*. K.A. Matis Ed., Flotation Science and Engineering, Marcel Dekker, Inc., 331–363.

FINCH J.A., 1995. *Column Flotation: A Selected Review, Part IV: Novel Flotation Devices*. Minerals Engineering, 8(6), 587-602.

FOX R.W., KLINE S.J., 1962. *Discussion: Flow Regimes in Curved Subsonic Diffusers*. ASME J. Basic Eng., 84, 303–312.

FUERSTENAU D.W., 1999. *The Froth Flotation Century*. Advances in Flotation Technology, Edited: B.K Parekh and J.D. Miller. Society of Mining, Metallurgy and Exploration Inc, Denver, Colorado.

GUO J.X., 2002. *Development and theory of centrifuga1 flotation cells*. PhD Thesis. Queen's University Kingston.

HARBORT G.J., MANLAPIG, E.V., DEBONO, S.K., 2002. *Particle collection within the Jameson cell downcomer*. Mineral Processing and Extractive Metallurgy, 111, 1,1-10.

JAMESON G.J., 1988. *New concept in flotation column design*. Minerals and Metallurgical Processing, 5, 44-47.

KAWATRA S.K., 2015. *Froth flotation–Fundamental principles.* Online: www.chem.mtu.edu/chem_eng/faculty/kawatra/Flotation_Fundamentals.pdf.

KLIMPEL R.R., 1995. *The Influence of frother structure on industrial coal flotation*. High-Efficiency Coal Preparation (Kawatra, ed.), Society for Mining, Metallurgy, and Exploration, Littleton, CO, 141-151.

KOWALCZUK P.B., BULUC B., SAHBAZ O., DRZYMALA J., 2014. *In search of an efficient frother for pre-flotation of carbonaceous shale from the Kupferschiefer stratiform copper ore*. Physicochemical Problems of Minerals Processing. 50(2), 835–840.

MILLER J.D., 1981. U.S. Patent No. 4,279,743, Washington, DC: U.S. Patent and Trademark Office.

MOHANTY M.K., HONAKER R.Q., 1999. *Performance optimization of Jameson flotation technology for fine coal cleaning*. Minerals Engineering, 12(4), 367-381.

NGUYEN, A.V., RALSTON, J., AND SCHULZE, H.J., 1997. *Elementary steps in particle-bubble attachment*. International Journal of Mineral Processing, 51, 183–195.

OTEYAKA B., 1993. *Modelisation D'une Colonne De Flottation Sans Zone D'ecume Pour La Separation Des Particules Grossieres*. PhD Thesis, Universite Laval, Quebec, Canada.

OTEYAKA B., SOTO H., 1995. *Modelling of negative bias column for coarse particle flotation*. Minerals Engineering, 8, 91-100.

OTEYAKA B., SAHBAZ O., UCAR A., BILIR K., GURSOY H., 2014a. *Design of jet difuser flotation column in pilot scale.* Electronic proceedings: XXVII. International Mineral Processing Congress, October 20-24, Santiago, Chile.

OTEYAKA B., SAHBAZ O., UCAR A., BILIR K., GURSOY H., 2014b. *Design of jet diffuser flotation column*. Proceedings of 14th International Mineral Processing Symposium, October 15 - 17, 2014, Kusadası, Turkey.

SCHULZE H.J., 1993. *Flotation as heterocoagulation process: possibilities of calculating the probability of flotation*. In B. Dobias (Ed.), Coagulation and flocculation (321-353). New York: Dekker.

SAHBAZ O., OTEYAKA B., KELEBEK S., UCAR A., DEMIR U., 2008. *Separation of unburned carbonaceous matter in bottom ash using Jameson cell*. Separation and Purification Technology, 62, 103-109.

SAHBAZ O., 2010. *Modification of downcomer in Jameson cell and its effect on performance*. PhD. Thesis, Dumlupinar University, Department of Mining Engineering, Turkey (In Turkish).

SAHBAZ O., ERCETIN U., OTEYAKA B., 2012. *Determination of turbulence and upper size limit in Jameson flotation cell by the use of Computational Fluid Dynamic modelling*. Physicochemical Problems of Minerals Processing, 48(2), 533-544.

SAHBAZ O., UCAR A., OTEYAKA B., 2013. *Velocity gradient and maximum floatable particle size in the Jameson cell.* Minerals Engineering, 41, 79-85.

SCHELUDKO A., TOSHEV B.V., BOJADIEV D.T., 1976. *Attachment of particles to a liquid surface (Capillary theory of flotation)*. Journal of the Chemical Society, Faraday Transactions 1: Physical Chemistry in Condensed Phases, 72, 2815–2828.

TRAHAR W.J., 1981. *A rational interpretation of the role of particle size in flotation*. International Journal of Mineral Processing, 8, 289-327.

WHITE F.M., 2005. *Fluid mechanics*, McGraw Hill, 826.