Hydrocyclone classification control

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Abstract. An overview of the classification systems in hydrocyclones in the copper ore enrichment departments at KGHM Polska Miedź S.A. was presented. In recent years, IMN has been conducting an investment - replacing hydrocyclones with modern HC hydrocyclone solutions - manufactured by ZAM Kęty and IMN. The results of implementing modern hydrocyclones are presented. The important issue is to define relation between values of pressure and/or hydrocyclone feed density and cut point achieved in these conditions for chosen classification node. By disposing this relation, implemented to classification monitoring system is possible to maintain cut point value within the range ± 5 % of assumed value by preserving acceptable feed variation in industrial conditions: - change of suspension density ± 20 % in ratio to assumed value, - change of feed particle size d80 ± 15 % in ratio to assumed value.

1. Introduction
Hydrocyclone classification requires a feed to be properly prepared and the process to be conducted under strictly controlled conditions with properly selected structural parameters. Classification is conducted at various stages in the enriching process. Hydrocyclones can be used in the classification of a number of mineral raw materials (e.g. ores of copper, zinc, lead, coal, sulphur, quartz, graphite), circulating water reclamation (clarification), and sewage treatment.

The development research, which was carried out, concerned a new technology for hydrocyclone classification process stabilisation using system for measuring grain size distributions of feed and classification products and also assessment of its capability for use in the copper ore enrichment process.

2. The aim of the investigations
Tested solution with the use of a three-product particle size analyzer consisted in the construction of a pilot installation based on the following basic components: HC 500/12° ZAM-IMN hydrocyclone cluster, three-product particle size analyzer system and “IMNCLASS” recording and computing system.

Technology of ore preparation to beneficiation is main stage of mineral processing. It decides about efficiency of useful minerals recovery as a result of proper liberation level of beneficiated minerals from gangue [1]. It also influences significantly on costs of concentrates production. Currently, processes of ore preparation to flotation contain crushing, screening, grinding in rod and ball mills, additional grinding of semi-products in pebble mills and hydraulic classification in spiral classifiers and hydrocyclones. The crucial influence on proper preparation of flotation feed has properly
conducted process of classification of ore suspension in hydrocyclones. In purpose of ensuring proper work of hydrocyclones the following parameters should be monitored: density of feed and classification products, feed pressure, hydrocyclone capacity, products particle size distribution.

Dependably on size of classified particles in Flotation Departments KGHM PM S.A. the hydrocyclones of cylindrical diameter being equal to 500 mm (for coarse particles) and 350 mm (for fine particles) are being applied, of various convergence angles of cone parts. To ensure appropriate capacity of systems, single hydrocyclones are grouped in batteries. Because of different lithologic composition of products of Comminution Departments, in Flotation Departments of KGHM PM S.A. O/ZWR various technological schemes are adapted to beneficiate material reach in sandstone fraction and of increased contents of carbonate fraction (Figure 1).

Currently for sandstone fraction, overflows of spiral classifiers are directed to first stage of classification in hydrocyclones ø 500 mm, from which overflows are feed for main flotation of sands and underflows after additional grinding in mills are feed for initial flotation of sands. Waste from initial flotation of sands is directed to second stage of classification of sands in hydrocyclones ø 500 mm. Overflows from these hydrocyclones are directed to main flotation of sands and underflows to additional grinding.

For carbonate ore wastes from initial flotation are directed to first stage of classification in hydrocyclones ø 500 mm, which overflows are classified in second stage of classification in hydrocyclones ø 350 mm and underflows are additionally ground in ball mills. Overflows of
hydrocyclones of second stage of classification are directed to main flotation while underflows are re-directed to first stage of classification of carbonates. Tailings from flotation I of carbonate cleaning are classified on third stage of classification in hydrocyclones ø 350 mm, from which overflows are directed to main flotation while underflows are additionally ground in pebble mill.

In KGHM PM S.A., because of lack of previous modernization, hydrocyclones classification systems characterize with relatively low sharpness of products separation. It influences on creation of big returns in grinding and additional grinding systems what causes shortening of grinding time and growth of energy consumption of production process. Classification sharpness influences significantly on quality of preparation of flotation feed. Growth of classification sharpness causes elongation of flotation time because of decreasing amount of material returns. It causes growth of copper recovery. Currently, classification sharpness in hydrocyclones is equal to about 82% and is upper value possible to achieve in industrial conditions. Even this value is hard to maintain because of various characteristics of feed parameters connected with previously conducted comminution and beneficiation processes and changes of characteristics of material treated by mineral processing.

Polish copper ores are mixtures of three lithological types: sandstones, carbonates and shales, which contents are changeable in ore dependably on exploitive fields.

The purpose of the task are identifying investigations of individual classification systems in range of determination of work characteristics concerning evaluation of their work efficiency in conditions of beneficiation of sandstone and carbonate copper ores in KGHM PM S.A. Efficiency of classification in hydrocyclones will be determined on the basis of obtained parameters of classification sharpness and cut point size in industrial conditions of changeable feed. The purpose of conducted researches is construction of database allowing elaboration of algorithms monitoring individual classification systems. The important aspect of the task is also finding possibility of simplifying classification process in hydrocyclones by only one level of classification will cause growth of technological and economic parameters of beneficiation process.

The main parameters being stabilized in hydrocyclones batteries are: feed pressure, feed density in sumps and levels in sumps [2]. Additionally, in monitoring systems the measurement of feed flow is available as well the evaluation of products particle size distribution. Stabilization of individual parameters occurs from the level of programming drivers PLC, by implementation of appropriate algorithms in regulation systems. The task of systems of pressure regulation in case of batteries equipped with knife gate valves is based on maintaining pressure in optimal, assumed range by means of monitoring of knife gate valves. The efficiency of battery work depends on capacity of the automatics system to maintain pressure within certain range as well on selection of this range. This range can be assumed manually as well it can be found by means of pressure optimization dependably on particle size distribution. In case of elaboration of monitoring algorithms the certain value of pressure can be searched which is optimal for battery work for which gate valves pressure monitoring system will select range and will maintain the calculated value within it. Similarly, the optimal values of feed density can be searched and its optimized value can be implemented to density regulation system which will stabilize it by means of monitoring water flow to sumps [3].

The important issue is to define relation between values of pressure and/or hydrocyclone feed density and cut point achieved in these conditions for chosen classification node. By disposing this relation, implemented to classification monitoring system is possible to maintain cut point value within the range ± 5 % of assumed value by preserving acceptable feed variation in industrial conditions:

- change of suspension density ± 20 % in ratio to assumed value,
- change of feed particle size d80 ± 15 % in ratio to assumed value.

After implementation of classification monitoring system on the basis of previously elaborated models the stage of industrial investigations will begin. It will verify the accepted models of sandstone and carbonate ores classification in hydrocyclones. The stabilization of hydrocyclone classification parameters and growth of separation sharpness to maximum value possible to achieve in certain
classification system will influence on growth of efficiency of beneficiation of sandstone and carbonate ores in KGHM PM S.A. Also, it is considered to elaborate assumptions with purpose of simplifying classification of carbonate ores in hydrocyclones by replacing two-stage classification system to only one level.

3. Introduction of the Hydrocyclones - ZAM IMN in copper processing plant
The innovative classification system consisting of new type HC 500/12° hydrocyclone batteries is equipped with parameter stabilization system that makes possible to control its proper operation, limit any disturbances and reach optimum technological indicators of the classification process [4]. Currently HC 500/12° hydrocyclone battery is operating in O/ZWR Lubin with high efficiency level of 90 - 95 % at required in O/ZWR regions effectiveness level of 85 %. Hydrocyclone HC 500/12° thickening and classifying hydrocyclone was designed in order to ensure increase of efficiency of grain classes separation in the products and stronger grain diversification in the hydrocyclone of such size. The diameter of the cylindrical part of 500mm is the basic hydrocyclone parameter. This size enables wide range grain and efficiency classification. The height of cylindrical part is equal to the diameter of the hydrocyclone. The hydrocyclone convergence angle has a significant impact both on efficiency and also on technological results of the equipment work. For hydrocyclone of diameter 500 mm the convergence angle is 12°. HC 500/12° hydrocyclone is equipped with composite anti-abrasive linings based on silicon carbide ensuring significant elongation of the equipment lifetime. Basing on the new hydrocyclone an innovative classification system consisting of Hc 500/12°hydrocyclones was built [4]. The system is equipped with parameter stabilization system that makes possible to control its proper operation and reach optimum technological indicators of the enrichment process. Parameter stabilization system makes possible to control the following parameters: pressure, density and quantity of the feed that is put in the hydrocyclone. Hc 500/12° hydrocyclone is adapted for classification of material characterized by diversified grain and density. HC 500/12° thickening and classifying hydrocyclone can be applied in the mineral resources enrichment and hydraulic classification in national and foreign plants dealing with mineral resources processing, circulating waters regeneration and waste water treatment. Advantages of the solution:
- increase of classification effectiveness,
- increase of equipment efficiency,
- longer hydrocyclone lifetime.

4. Results of sample of the classification system in hydrocyclones in copper ore enrichment plants
Under the OPTICLASS project, a review of the classification systems at KGHM copper enrichment plants. An example of the results of testing the classification system - Rudna region is presented in Table 1.

| ZWR Rudna area (A side - technological line) |
| Classification stage: I ° classification of sandstone ores (classification of the overflow classifier) |
| Hydrocyclone type: HC500 / 20 ° |
Table 1. Results of testing carried out to determine the classification parameters in hydrocyclones, broken down into sandstone and carbonate ore classification at KGHM PM S.A. (selected example).

| No | Grain class (mm) | Grain average (mm) | Sieve analysis (mm) | Yield (mm) | d80 (mm) | Ec (d80) (%) |
|----|------------------|--------------------|---------------------|------------|----------|---------------|
| 1  | 1.00 - 0.50      | 0.750              | 10.0 - 0.00         | 0.07       | 0.12     | 0.00          |
| 2  | 0.50 - 0.32      | 0.408              | 0.00 - 1.50         | 1.00       | 1.35     | 0.99          |
| 3  | 0.32 - 0.20      | 0.258              | 8.60 - 17.30        | 1.40       | 16.19    | 0.73          |
| 4  | 0.20 - 0.16      | 0.180              | 11.20 - 21.30       | 3.10       | 19.97    | 2.30          |
| 5  | 0.16 - 0.10      | 0.130              | 29.90 - 36.00       | 8.50       | 27.53    | 9.40          |
| 6  | 0.10 - 0.071     | 0.086              | 6.90 - 10.80        | 5.10       | 9.99     | 5.33          |
| 7  | 0.07 - 0.045     | 0.058              | 7.10 - 5.00         | 6.20       | 6.02     | 6.61          |
| 8  | 0.05             | 0.023              | 32.90 - 7.10        | 7.56       | 32.80    | 7.13          |

**Yield:**
- **overflow:** 37.48%
- **underflow:** 62.52%

Correlation coefficient: \( R = 0.9832 \)

**d(50) = 0.659 mm**

![Grain distribution curve](image)

Table 2. Classification parameters in ZWR KGHM - sampling results, Battery HC-111B.

| Ore type | Plant name | Hydrocyclones classification stage | Feed (N) (P - Overflow, W - Underflow) | d80 [mm] | Ec (d80) [%] |
|----------|------------|-----------------------------------|----------------------------------------|----------|--------------|
| Ruda piaskowca | Lubin | Classification in milling circuit | N: underflow MD, P: rougher flotation, W: additional milling | 0.17 | 60.4 |
| | | Iº classification (initial flotation waste) | N: initial flotation waste, P: rougher flotation, W: additional milling | 0.165 | 68.9 |
| | | classification (Main flotation waste) | N: waste rougher flotation, P: final waste, W: additional milling | 0.135 | 65.3 |
| Rudna | Iº classification (classifier overflow) | N: spiral classifier overflow | 0.14 | 78.1 |
| Classification (waste from milling circuit) | P: rougher flotation | W: additional milling |
|------------------------------------------|---------------------|----------------------|
| II° classification (classification in the milling circuit) | N: initial flotation waste | 0.16 – 0.18 |
| | P: rougher flotation | 55.2 – 67.9 |
| | W: additional milling | |
| I° classification (waste from preliminary flotation) | N: initial flotation waste | 0.21 |
| | P: classification in milling circuit | 68.3 |
| | W: additional milling | |
| Flotation semi-product classification | N: flotation semi-products | 0.05 – 0.055 |
| | P: rougher flotation | 76.2 – 77.9 |
| | W: additional milling | |
| Milling circuit classification | N: underflow MD (additional mill) | 0.08 – 0.20 |
| | P: rougher flotation | 60.8 – 84.2 |
| | W: additional milling | |
| Milling circuit classification (Underflow of ball mill classification) | N: underflow MK (ball mill) | 0.22 |
| | P: flash flotation | 68.6 |
| | W: additional milling | |
| II° classification (flash flotation waste classification) | N: flash flotation waste | 0.15 |
| | P: rougher flotation | 60.8 |
| | W: additional milling | |
| III° classification (semi-product of initial flotation and waste from I scavenger flotation) | N: semiproduct of rougher flotation + waste I scavenger flotation | 0.10 |
| | P: rougher flotation | 73.8 |
| | W: additional milling | |
| Classification (waste of milling circuit flotation) | N: waste from flotation in milling circuit | 0.18 |
| | P: rougher flotation | 49.4 |
| | W: additional milling | |
| Classification in milling circuit (classification of underflow from ball mill) | N: underflow MK | 0.23 |
| | P: initial flotation | 52.0 |
| | W: additional milling | |
| I° Classification | N: initial flotation waste + underflow of I° classification | 0.08 – 0.17 |
| | P: II° classification | 63.5 – 76.2 |
| | W: additional milling | |
| II° Classification | N: overflow HC | 0.10 – 0.14 |
| | I° classification | 69.9 – 78.0 |
### Table 3. Parameters of pilot hydrocyclone.

|                          | Capacity of HC cluster [m³/h] | Feed density [g/dm³] | Required overflow density [g/dm³] | Required underflow density [g/dm³] |
|--------------------------|--------------------------------|-----------------------|----------------------------------|-----------------------------------|
| Mean value               | 575                            | 1225                  | 1085                             | 1700                              |

Figure 2 shows the hydrocyclone cluster location in the flowsheet of ore preparation for flotation.
Figure 2. Location of the pilot installation, classification assessment and control system.

Figure 3 presents photographs of hydrocyclones installed in KGHM Polska Miedź SA.

The system is designed to keep the fixed setpoint of (Table 3)
- P80 grain size of hydrocyclone overflow;
- \(d_{50}\) cut size of classification;
- total classification efficiency coefficient Ec for P80 grain size of hydrocyclone overflow.

Dependence of technological indicators of the separation process in the hydrocyclone on its design parameters and properties of the feed is shown in Table 4.
Table 4. Denotations of the preset essential operating parameters for the IMNCLASS system.

| Indicator | Parameter | Regulator of cut size | Preset \(d_{50}\) cut size [mm] | Regulator insensibility zone, preset [mm] | SP change value of pressure regulator, preset [kPa] |
|-----------|-----------|-----------------------|----------------------------------|---------------------------------------|----------------------------------|
| P80       | \(d_{50}\) | Regulator of P80 grain size of hydrocyclone overflow | Preset P80 grain size [mm] | Regulator insensibility zone, preset [mm] | SP change value of pressure regulator, preset [kPa] |
| Ec        | Ec        | Regulator of total classification efficiency Ec for P80 grain size | Preset value of Ec [%] | Regulator insensibility zone, preset [%] | SP change value of pressure regulator, preset [kPa] |

Table 5. Dependence of technological indicators of the separation process in the hydrocyclone on its design parameters and properties of the feed.

| Indicator | Parameter | \(V_{zn}\) | \(V_{zw}\) | \(V_{zp}\) | \(d_{50}\) | \(\gamma_w\) | \(\gamma_p\) | \(\alpha_w\) | \(\alpha_p\) | \(E_p\) |
|-----------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------|
| \(D\uparrow\) |            | \(\uparrow\) | \(\uparrow\) | \(\uparrow\) | -           | -           | -           | -           | -           | -      |
| \(d_o\uparrow\) |            | \(\uparrow\) | \(\uparrow\) | \(\uparrow\) | (\(\uparrow)\) | (\(\downarrow\)) | \(\uparrow\) | -           | -           | -      |
| \(d_p\uparrow\) |            | (\(\uparrow)\) | \(\downarrow\) | \(\uparrow\) | \(\downarrow\) | \(\uparrow\) | \(\uparrow\) | \(\uparrow\) | -           | -      |
| \(h_p\uparrow\) |            | -           | -           | -           | \(\uparrow\) | \(\downarrow\) | \(\uparrow\) | \(\uparrow\) | \(\uparrow\) | \(\uparrow\) |
| \(d_w\uparrow\) |            | -           | \(\uparrow\) | \(\downarrow\) | \(\downarrow\) | \(\uparrow\) | \(\downarrow\) | \(\downarrow\) | \(\downarrow\) | \(\uparrow\) |
where:
\( d_0 \) [mm] - variable diameter of the overflow nozzle
\( P \) [bar] - pressure
\( P_{80} \) - grain size \( P_{80} \) in overflow [mm]
\( Ec(P_{80}) \) [%] - total classification efficiency for \( P_{80} \)
\( V_{oz}, V_{uw}, V_{zp} \) - volume discharge of overflow, underflow and feed [%]
\( \gamma_w, \gamma_p \) - mass yield of overflow, underflow and feed [%]
\( \alpha_w, \alpha_p \) - density of overflow, underflow and feed [g/dm³].

Data gathered by the IMNCLASS recording, computing and control system were used for developing the industrial classification process control models [7,8]. Data were selected and gradated as averages from periods of stable plant operation and stable feed (\( d_80 \) grain size variability did not exceed ±15%). The process data for verification were sorted in ascending order by hydrocyclone inlet pressure and presented in Table 6.
Table 6. Process data.

| p [kPa] | d50 [mm] | P80 [mm] | Ec [%] |
|---------|----------|----------|--------|
| 80      | 0.1454   | 0.0842   | 85.7   |
| 95      | 0.1574   | 0.0849   | 87.6   |
| 105     | 0.1555   | 0.0833   | 87.8   |
| 110     | 0.1564   | 0.0979   | 84.7   |
| 115     | 0.1684   | 0.0928   | 87.2   |
| 120     | 0.1916   | 0.0989   | 85.2   |
| 125     | 0.1617   | 0.0902   | 86.6   |
| 135     | 0.1689   | 0.0964   | 88.8   |
| 145     | 0.2000   | 0.0994   | 87.4   |
| 150     | 0.2307   | 0.1221   | 86.4   |

An important aspect of verification of the control system based on the developed models is the continuous analysis of the technological parameters of the classification, e.g. d50 split grain, EC (P80) [%] or P80 grain in hydrocyclone transfer.

6.1 Data analysis

The results obtained from ongoing production, i.e. data matrixes gathered and computed by the IMNCLASS recording [4], computing and control system, and data derived from models are the basis of the analysis for the classification system under investigation. To verify and enable the proper assessment of the process data obtained in the actual industrial conditions at a selected classification point, the process (industrial) data were compared with those derived from models. There are presented below examples of the calculations of d50 cut size and P80 grain size of hydrocyclone overflow based on linear and polynomial models and based on data obtained by the IMNCLASS control system.

Model 1

d50 as a function of p; linear model.
d50 cut size of hydrocyclone classification depending on feed pressure (for d0 125 mm inlet).

\[ d_{50} = 0.00099p - 0.056R^2 = 68.16\% \]

Model 2

d50 as a function of p; polynomial model.
d50 cut size of hydrocyclone classification depending on feed pressure (for d0 125 mm inlet).

\[ d_{50} = 0.000016p^2 - 0.0027p + 0.266R^2 = 76.78\% \]

The variability of d50 obtained by the IMNCLASS system and derived from models is presented in Figure 4.
7. Summary

The studies carried out indicate that it is possible to use the IMNCLASS system for optimising the hydrocyclone classification process. It allows hydrocyclone operation control based on parameters directly connected with feed and classification products. Hydrocyclone operation is characterised by overall hydrocyclone capacity and quantitative product separation in the hydrocyclone. The mentioned parameters depend on hydrocyclone design as well as on the properties of the ore which is being processed. The developed IMNCLASS hydrocyclone classification process control system can be used effectively for assessing this process and as a control system tool. The interrelationships between all physical and process parameters of hydrocyclone operation should be considered. It is of utmost importance when choosing a hydrocyclone for a specified task at the design concept stage and also for adjusting its operation in real-life conditions. Quality improvement and classification technology stability should also have an important effect on circulation changes of product streams directed to further processing and on the results of the operations performed, including finished products. The enrichment process is conducted by a number of machines and devices that do not guarantee the stability of enrichment final indexes despite the advanced control and monitoring technologies used. The specificity of enriched ore results in process variability to which the parameters of individual process operations should be adjusted, and classification optimization is an important action in this field.

References

[1] Trybalski K 2009 Kontrola, modelowanie i optymalizacja procesów technologicznych przeróbki rud, AGH University of Science and Technology Press, Kraków
[2] Tumidajski T, Foszcz D, Jamróz D, Niedoba T and Saramak D 2009 Niestandardowe metody statystyczne i obliczeniowe w opisie procesów przeróbki surowców mineralnych, IGSMiE PAN Publishing House, Kraków
[3] Nowak Z 1970 Klasyfikacja hydrauliczna w obiegu wodno-mułowym i technologiczne kryterium jej stosowania, Górnictwo 43, Silesian University of Technology, Zeszyt Naukowy 288, Gliwice
[4] Szczerba E, Wieniewski A, Łuczak R, Mańka A and Zachariasz T 2013 Badania innowacyjnego układu klasyfikacji w hydrocyklnach klasyfikująco-zagęszczających w technologii wzbogacania rud miedzi, IMN Report No 7155/13, Gliwice
[5] Woch M and Tomaka W 2013 Opracowanie systemu sterowania pracą baterii hydrocyklnów, IMN Report No 7210/13, Gliwice
[6] Wieniewski A and Myczkowski Z 2017 Achievements and Participation in the Development of
Mineral Processing and Waste Utilization of the Institute of Non-Ferrous Metals in Gliwice, *Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society*, No 2(40), pp. 15-24

[7] Krawczykowski D 2017 Application of Diffraction Laser Analysis to Monitor Granulation of Copper Ores Processing Products, *Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society*, No 1(39), pp. 233–240.

[8] Niedoba T, Tumidajski T and Surowiak A 2016 Mathematical models of hydrocyclone performance in various copper ores preparation circuits, E3S Web of Conferences, Vol. 8 art. No. 01028, pp. 1–8., https://goo.gl/23FUE4 [2019-07-06]

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