Evaluation of jig work on the basis of granulometric analysis of particle size fractions of beneficication products in purpose of process optimization

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Abstract. The analysis of hard coal jigging was conducted because of optimal recovery of useful fraction in concentrate and not useful fraction in tailings. The evaluation of the process was conducted on the basis of industrial sampling of coal dust jig and performed granulometric and densimetric analyses of collected products samples in laboratory conditions. In selected size-density fractions of partition products the yields of products were calculated and the amounts of ash and total sulfur were determined. On the basis of the results of granulometric, densimetric and chemical analyses of obtained size-density fractions, balance of partition products and appropriate calculations the beneficiation curves were created which allowed to evaluate the process because of optimization of device work in purpose of achieving higher recovery by possibly highest concentrate quality.

The evaluation of hard coal beneficication results was done in the paper because of optimal recovery of organic phase in concentrate and mineral componenets in tailings in aspect of process monitoring. The analysis of obtained characteristics of ability to beneficication was performed in purpose of selecting optimal technological factors for the needs of optimization of device work.

1. Introduction

The efficiency of beneficication of mineral raw materials is connected in each case with its susceptibility to beneficication, so mainly with variation of useful properties of the material being beneficiated in dedicated technological system. This differentiation of properties in aspect of physical, geometrical and other features allows, apart from obvious separation of useful and not useful components, to achieve assumed level of beneficication which determines economic efficiency of the process. Because of this the necessity of determining optimal beneficication factors occurs which would make possible to determine the potential ability of material to beneficication. These actions are necessary in purpose of achieving maximal use of the deposit of certain raw material. Because of the fact that possibly high accumulation of not useful parts in tailings is more and more important the appropriate tools to evaluate efficiency of certain technological process to realize production task are needed to be found [2, 3, 7, 8]. These actions should be concentrated on process optimization in context of changeable parameters of the feed what causes necessity of appropriate process changes adjusting the device work to actual requirements in this range which occur from the characteristics of the feed being directed to beneficication. This requires detailed analysis of the results of beneficication.
process conducted in the device dependably on feed properties allowing to determine optimal work points being appropriate for these changeable properties of the beneficiated product. To analyze efficiency of the partition of the components occurring in raw material the beneficiation curves can be applied, like Fuerstenau curves or Halbich curves which can be used by evaluating the quality of separation products. The Fuerstenau curve is presented by the relation \( \varepsilon = f(\varepsilon_0) \), where

\[
\varepsilon = \left( \frac{\alpha - \vartheta \beta}{\beta - \vartheta \alpha} \right) \cdot 100 \quad \text{and} \quad \varepsilon_r = \left( 100 - \frac{\alpha - \vartheta \beta}{\beta - \vartheta \alpha} \right) \frac{100 - \vartheta}{100 \alpha} \tag{1}
\]

It is usually applied by evaluating ores flotation, similarly as Halbich curve which presents relation \( \varepsilon = f(\beta) \). Halbich and Fuerstenau curves do not have any extreme points and that is why determination on their basis of extreme beneficiation factors values is impossible.

From the properties of Halbich curve occurs that the characteristic separation point is the point of biggest curvature, marked as point \( f_H \) [5]. According to the formula determining the curvature radius it is a point in which second derivative of recovery calculated in accordance to concentrate grade achieves minimal value. According to Kelly and Spottiswood [6] this point can be determined on the basis of maximal value of the parameter \( f = \frac{4\beta}{100} \) for which the curve tangent to Halbich curve is obtained. For Fuerstenau curve the optimal point can be point of the biggest radius \( f_F \) – it is a point in which more gangue starts to occur in concentrate than useful component.

The Fuerstenau curve allows also different ways of determining technologically optimal quality of a concentrate. The point of biggest radius \( f_F \) can be determined as in case of Halbich curves or the optimal point \( F \) is determined [1], which lies on the crossing of real beneficiation curve with diagonal of identity of useful component recovery in concentrate and recovery of remaining components in tailings. In optimal point \( F \) the recovery of analyzed component in concentrate is equal to recovery of remaining components in tailings. The partition efficiency curve based on a sum of recoveries of useful component in concentrate and residuals in tailings achieves extreme value, which is in contrast to curves described above. It can be treated as technological optimal point [3, 4]. The proposed beneficiation characteristics basing on efficiency factor of this process (recovery of useful component in concentrate + recovery of residuals in tailings – 100), because of its parabolic course (clearly visible optimal point for extreme course of factor in function of concentrate quality - \( f_F \)) is convenient in application to evaluate obtained beneficiation characteristics, especially when various technologies of beneficiation or various parameters of separation process conductance are to be compared.

2. Materials and methods

The industrial experiment was conducted which was based on sampling of coal dust jig working in three products way in one of coal mechanical processing plant. The samples of concentrate, middlings and tailings were collected and then the densimetric analysis was performed in zinc chloride solutions for all jigging products obtaining fractions of density -1.3; 1.3-1.4; 1.4-1.5; 1.5-1.6; 1.6-1.7; 1.7-1.8; 1.8-2.0 and +2.0 [Mg/m³]. Each density fraction was screened on appropriate set of sieves what allowed to obtain narrow size-density fractions. In each of them chemical analysis was performed for ash and total sulfur contents. The balance of partition products according to yields and grades of, respectively, ash and sulfur for certain size and density fraction allowed to determine parameters of the jigging feed. The mean ash content in feed was equal to about 46% and mean sulfur content was equal to 4.8%.

The capacity of device work was equal to 500 [Mg/h], amount of delivered bottom water – 218 [m³/h] and constant number of pulsations was 26 cycles per minute.

3. Results and discussion

The obtained results allowed to calculate coordinates and draw Fuerstenau and Halbich beneficiation curves as well curve of selectivity presenting sum of useful component recoveries in concentrate and
of remaining components in tailings in function of component content in concentrate. Additionally, also partition curves for the feed and narrow particle size fractions were calculated and drawn in purpose of comparing preciseness of separation in a jig. These characteristics were presented for the feed and for selected narrow particle size fractions.

The certain characteristics presented in this paper allowed to determine described points in which technological optimum is realized by various criteria. The purpose of presented considerations and conducted calculations was to determine optimal points on beneficiation curves allowing more precise determination of potential possibilities of the material in aspect of obtaining certain values of technological factors of separation process course. In consequence, it makes possible to control the process in purpose of optimization of its results. The calculations were done for individual particle size fractions of the feed delivered to jigging process what allowed to analyze its efficiency in function of processed material particle size distribution.

Figure 1 presents the obtained beneficiation curves with determined points of optimal device work for the feed and Figure 2 shows analogical curves for narrow particle size fractions after jigging. On the basis of the obtained data the coordinates were calculated and partition curves were drawn for the feed and individual particle size fractions what is shown on Figure 3.

Figure 1. Beneficiation curves for the feed: a) Fuerstenau, b) Halbich, c) curve of beneficiation selectivity.
fraction 3.15-5.00 mm

fraction 5.00-6.30 mm

fraction 6.30-8.00 mm

fraction 8.00-10.00 mm
Figure 2. Beneficiation curves: a) Fuerstenau, b) Halbich, c) curve of beneficiation selectivity.

Table 1 contains the values of selectivity factor $F$ and maximal curve radius $f_F$ as well $f_H$ – point of biggest curvature and optimal point for extreme course of relation of the factor in function of concentrate quality – $f_S$. On the basis of these criteria and partition preciseness factor determined from
The analysis of coal dust beneficiation was done in individual particle size fractions. The presented data indicate that the most efficient separation of ash from organic phase occurred in particle size fractions 2.00-3.15 mm and 3.15-5.00 mm. The values of the factors $F$ and $f_F$ in these fractions were the highest. In particle size fractions from the range 5.00 till 10.00 mm the results of beneficiation were good too. The lowest values of the factor $F$ lower than 70 were observed for particles of size 10.00-12.50 mm and for the finest particle size fraction <2.00 mm which do not suppose to occur in the jigging feed. However, because of the mineral character of the coal and its susceptibility to uncontrolled crushing and soaking fine particles are created which adversely influence on beneficiation effects. The preciseness of partition determined on the basis of partition curves and imperfection factor indicates good separation sharpness, especially for fractions above 8.00 mm.

\[ \text{Figure 3. Partition curves a) for feed b) for narrow particle size fractions.} \]

The analysis of correlation between ash content and sulfur content in the feed and particle size fractions presented on Figure 4 and values of correlations index shown in Table 2 indicate strong connection between analyzed parameters, especially in individual fractions 2.00-10.00 mm from the granulation range. It can affect on selective separation of sulfur with mineral phase from coal. This issue will be the subject of future analyzes of efficiency of beneficiation by means of various criteria of evaluation in aspect of control process of coal dusts jigging.
Table 1. Technologically optimal values of the factors determined according to various criteria in particle size fractions.

| Beneficiation curve/parameters | Criterion of evaluation | Feed | Particle size fraction [mm] |
|-------------------------------|-------------------------|------|---------------------------|
|                               |                         | < 2.00 | 2.00-3.15 | 3.15-5.00 | 5.00-6.3 | 6.30-8.00 | 8.00-10.00 | 10.00-12.50 | 12.50-16.00 | 16.00-20.00 |
| Recovery of flammable parts in concentrate & recovery of ash in tailings | $F$ | 74.5 | 69.5 | 80 | 80.3 | 77.8 | 74.8 | 74.8 | 62.8 | 71.5 | 77.8 |
| Recovery of flammable parts in concentrate & flammable parts grade in concentrate 100-9 | $f_R$ | $e=62$; $e'=55$; $e=71$; $e=75$; $e=68$; $e=63$; $e=61$; $e=52$; $e=61$; $e=70$; | $e'=91$ | $e'=94$ | $e'=92$ | $e'=91$ | $e'=95$ | $e'=95$ | $e'=96$ | $e'=90$ | $e'=90$ |
| Sum of recoveries of flammable parts in concentrate and remaining components in tailings & flammable parts grade in concentrate 100-9 | $f_H$ | $e=72$; $e=62$; $e=84$; $e=83$; $e=73$; $e=66$; $e=66$; $e=53$; $e=62$; $e=73$; | $e'=80$ | $e'=83$ | $e'=86$ | $e'=88$ | $e'=90$ | $e'=86$ | $e'=90$ | $e'=80$ | $e'=78$ |
| Imperfection                  | I | 0.07 | 0.08 | 0.08 | 0.086 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 | 0.09 |
Figure 4. Graphs of linear regressive functions for sulfur contents in function of ash contents.

Table 2. Values of Pearson linear correlation index $r$ between ash contents and sulfur contents for individual particle size fractions and the feed.

| Particle size fraction [mm] | < 2.00 | 2.00-3.15 | 3.15-5.00 | 5.00-6.30 | 6.30-8.00 | 8.00-10.00 | 10.00-12.00 | 12.00-16.00 | 16.00-20.00 | Feed |
|----------------------------|--------|-----------|-----------|-----------|-----------|------------|-------------|-------------|-------------|-------|
| $r$                        | 0.889  | 0.996     | 0.994     | 0.996     | 0.988     | 0.988      | 0.762       | 0.680       | 0.406       | 0.926 |
4. Conclusions
The presented method of jig work evaluation allowed to determine most beneficial values for technological factors of separation process course allowing to control the process in purpose of optimization of obtained results for industrial raw material beneficiation. The conducted densimetric analysis in particle size fractions for the products of three-product jigging allowed to determine conditions in aspect of efficiency of industrial jigging considering particle size distribution of the feed being directed to the process.

The results of analysis indicate that the most beneficial are feed particle size distributions from 8.00 till 16.00 mm giving high efficiency of the process conductance measured by partition sharpness index. The most beneficial values of technological indexes (recovery of useful component) of beneficiation were obtained for sizes 2.00-3.15 mm and 3.15-5.00 mm.

The presented methodology of beneficiation curves shows spectrum of possibilities of selecting an efficient tool to evaluate the beneficiation for both ores and coal. However, it is worthy to pay attention to selection of one criterion of evaluation because the evaluation of the process dependably on various assumed factors can lead to differences in evaluating efficiency of certain process. It has a crucial meaning for the analysis of industrial results which characterize with specific course.

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