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THE ANALYSIS OF COAL FINES SEPARATION PRECISION EXPOSED TO CHANGEABLE HYDRODYNAMIC PARAMETERS OF JIG WORK

ANALIZA DOKŁADNOŚCI ROZDZIAŁU MIAŁÓW WĘGLOWYCH W ZALEŻNOŚCI OD ZMIENNYCH PARAMETRÓW HYDRODYNAMICZNYCH PRACY OSADZARKI

In technology of coal fines beneficiation in Poland mainly fines jigging processes are in use. In case of steam coal fines beneficiation it is till 80% of the whole amount of produced assortments, while in case of coking coal fines it is 100%.

The necessary condition of not homogenous feed separation which is directed to beneficiation process in pulsating water stream is a sufficient liberation of particles. The stratification of particles in working bed causes that particles of certain size, density and shape gather in individual layers in working bed of jig. The introduction of sufficient amount of additional water determines appropriate liberation of particles group, which generates partition into concentrate and tailings.

The paper presents the results of sampling of industrial jig used for the beneficiation of coal fines by three various settings of additional amount of water under sieve which is directed to jigging. These amounts were equal to 35, 50 and 70 [m^3/h]. Collected samples of separation products were then sieved into narrow particle size fractions and divided into density fractions. In such narrow size-density fractions the coordinates of partition curves were calculated for tailings of hard coal fines, which were subsequently approximated by means of Weibull distribution function. The separation precision measured by separation density, probable error and imperfection were determined on the basis of obtained model separation curves. The evaluation of separation effects was performed for a wide particle size fraction: feed directed to jigging process and narrow particle size fractions. The analysis of separation results in size-density fractions allowed to determine the influence of particle size change on the value of probable error. The results of separation precision in size-density fractions were compared with effects of separation of wide particle fraction, i.e. feed directed to jigging process.

Keywords: jig, particle size, separation precision, probable terror, Weibull distribution function

W technologii wzbogacania miałów węglowych w Polsce wykorzystuje się głównie procesy separacji w osadzarkach miałowych. W przypadku wzbogacania miałów węgla energetycznego jest to do ok. 80% całości produkowanych sortymentów, natomiast miały węgla koksowego wzbogaca się w 100%.

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Warunkiem koniecznym rozdziału nadawy niejednorodnej kierowanej do wzbogacania w pulsującym strumieniu wody jest dostateczne rozluzowanie ziaren. Stratyfikacja ziaren w łożu roboczym powoduje, że ziarna o określonej wielkości, gęstości i kształcie grupują się w odpowiednich warstwach w łożu roboczym osadzarki. Doprowadzenie odpowiedniej ilości wody dodatkowej warunkuje prawidłowe rozluzowanie grupy ziaren, co w rezultacie generuje podział na koncentrat i odpad.

W artykule przedstawiono wyniki opróbowania osadzarki przemysłowej wzbogacającej miały węglowe przy trzech różnych ustawieniach dodatkowej ilości wody podsitowej podawanej do osadzarki równej 35, 50 i 70 [m^3/h]. Pobrane próbki produktów rozdziału rozsiano na wąskie klasy ziarnowe i podzielono na frakcje gęstościowe. W wąskich klaso-frakcjach wyliczono współrzędne krzywych rozdziału dla odpadów miałów węgla kamiennego, które aproksymowano rozkładem Weibulla. Dokładność rozdziału mierzoną gęstością rozdziału, rozproszeniem prawdopodobnym i imperfekcją określono na podstawie uzyskanych modelowych krzywych rozdziału. Dokonano oceny efektów rozdziału dla szerokiej klasy ziarnowej – nadawy kierowanej do separacji w osadzarce oraz dla wąskich klas ziarnowych. Analiza rezultatów separacji w klaso-frakcjach pozwoliła na określenie wpływu zmiany wielkości ziaren na wartość rozproszenia prawdopodobnego. Wyniki dokładności rozdziału w klaso-frakcjach porównano z efektami separacji szerokiej klasy ziarnowej – nadawy kierowanej do osadzarki.

Słowa kluczowe: osadzarka, wielkość ziaren, dokładność rozdziału, rozpzroszenie prawdopodobne, rozkład Weibulla

1. Introduction

The exploited coal output characterizes with differentiation of the both physical (particle size) and qualitative properties (calorific value, ash contents, sulfur contents, moisture). Raw coal very often cannot be directly used because of the fact that it contains many pollutants. Differentiated contents of clean coal particles, gangue and outgrowths determine selection of appropriate methods and work parameters of devices during beneficiation processes. In case of steam coal the coal fines are the main product which are separated on the basis of beneficiation technology in various sorts of coal fines jigs, which are produced in Poland (Osoba, 2017). The beneficiated coal fines are the main part of multi-component energetic mixtures being used for the energetic purposes if they fulfill certain qualitative parameters. However, raw coking coal fines are not suitable to direct application in coking processes. This industry has strict qualitative requirements for coals directed to coking process (Blaschke, 2009). That is why it is very important to control beneficiation effects of hard coal fines in jigs because on their basis the final products are obtained. Furthermore, beneficiation based on reduction of ash and sulfur contents increases the market value of the product and is the first stage of production of clean coal technologies. Because of the problems presented above the issue of coal fines jigging preciseness is the subject of this paper.

The jigging process occurs in vertical pulsing medium motion which is a pseudo-suspension of separated grained material in water. After some time of such motion the stratification of particles set into subsets occurs, which differ by physical (density) and geometrical properties (particle size, shape coefficients) (Leyman, 1992; Xia et al., 2007; Panda et al., 2012). The very important feature is way of measuring partition density and partition products receipt (Cierpisz & Joostberens, 2015).

In the case of ideal beneficiation of raw materials, the separation into products occurs according to a precisely determined partition limit, which includes, for example, a density of material particles. The particles of lower density occur in concentrate and the particles of higher density in tailings (in the case of coal). However, in industrial conditions, it is practically impossible to do because, apart from differences in particle densities, other parameters also influence the final effect of the process such as: various size and shape of particles, porosity, mutual mechanical interactions between particles, turbulence, load of feed, too big or too small amount of water in working bed of jig and many other. All of these factors contribute to the fact that particles of precisely determined density are not concentrated in an appropriate layer. As a result of scatter, they come in layers, and as a consequence in separation products, where they were not supposed to occur. In this way they decrease the precision of the process. The appropriate level of liberation in working bed of jig allows particles to move freely during cycles of raise and descent. Required liberation can be obtained through introduction of appropriate amount of additional water.

The separation factors can be used to analyze separation efficiency. The most common and most often used are the factors based on partition curves (Drzymała, 2007).

2. Materials and methods

The researched material – coal fines – characterized with mean ash contents being equal to about 44.7% and mean sulfur contents equal to 2.2%.

Experimental investigations of separation precision of coal fines in jig measured by separation precision factors obtained from partition curve were based on sampling of industrial three-product jig manufactured by Allmineral of working surface equal to 17m^2. The device worked in one of the Polish hard coal mines. The experiments were conducted by keeping constant number of pulsations equal to 26 cycles per minute. The system capacity (flow intensity) was equal to 300 [Mg/h]. Samples of separation products were collected by three various amounts of water under sieve in individual experiments. These amounts were 35, 50 and 70 [m^3/h]. With parameters determined in such a way, after stabilization of the process, the samples of concentrate, middlings and tailings were collected simultaneously within 3 minutes. Next, each of the products was analyzed for density and particle size. The float and sink analysis was performed in solutions of zinc chloride of densities 1.3, 1.4, 1.5, 1.6, 1.7, 1.8 and 2.0 [Mg/m^3], respectively. Each density fraction was then screened on sieves of mesh 2.0, 3.15, 5.0, 6.3, 8.0, 10.0, 12.5, 16.0, 20.0 and 25.0 [mm]. In such way about 240 fractions were obtained from each experiment, which allowed to calculate coordinates of partition curves and then their plotting in narrow particle fraction and for the whole amount of separated material. For the purpose of this work the coordinates were calculated and partition curves were plotted for the coal fines tailings produced by jigging process. For the tailings the partition number is given by the equation:

$$T_\rho = \frac{n_T}{n_F} \tag{1}$$

where: T_ρ — partition number for particles of density ρ, n_T — number of particles of density ρ occurring in tailings, n_F — number of particles of this density in feed.

Equation (1) presents the probability of occurring of particle of density ρ in tailings. The relation between partition number and particle density is presented by partition function and its graphical image is partition curve.

The partition preciseness factors were calculated on the basis of partition curves, using the formulas:

– probable error E_p:

$$E_p = \frac{\rho(T_{75}) - \rho(T_{25})}{2} \tag{2}$$

– imperfection I:

$$I = \frac{E_p}{\rho_{50}} \tag{3}$$

where: — densities of particles which with probability being equal to 75% and 25%, respectively occur in tailings, ρ_{50} — partition density.

As the investigations of other authors show (Paul et al., 1998; Gotfried, 1978), the partition curves for jigs with density treated as separation feature are asymmetric curves and they can be well approximated by means of Weibull distribution curves. As a result, the Weibull distribution function was used for this purpose, whose general form is given by the equation (4):

$$T(\rho) = 100\left\{1 - \exp\left[-\left(\frac{\rho}{\rho_o}\right)^n\right]\right\} \tag{4}$$

where: ρ_o and n – parameters of Weibull distribution function

3. Results and discussion

Mass yields of size-density fractions for obtained products from all jigging experiments were presented in Tables 1, 2 and 3. The data characterizing the feed were calculated on the basis of balance calculations (Stępiński, 1964). The obtained results allowed to calculate yields of separation products of coal fines jigging, which were shown in Table 4. The highest yield of concentrate, which was equal to about 40%, was obtained by addition of water in amount of 50 m^3/h and the lowest one – above 25% – by addition of water in amount of 70 m^3/h.

On the basis of data presented in Tables 1-3 the coordinates of partition curves were calculated for tailings in individual particle size fractions as well for tailings separated from the feed of coal fines processed by jigging. By calculating the coordinates the middlings obtained during the separation process were qualified as tailings because their quality was low.

The plots of distribution functions of partition curves were presented in Figs. 1-6. On these plots the model relation is presented by the continuous curve. The curvilinear correlation index is bigger than 0.95. Using the approximated partition curves the separation precision factors were calculated and the values of these parameters were presented in Figs. 1-3, plotted for coal fines separated by jigging. These parameters were separation density ρ_r, probable error E_p and imperfection I. Looking at the values of these parameters it seems that with the higher amount of additional water the values of separation precision factors lower, especially the values of probable error and imperfection. This means that the separation precision is higher thanks to jigging. For separated narrow particle fractions similar partition curves were plotted for tailings for each particle fraction. Analogically, as in the previous case, the empirical points were approximated by means of Weibull distribution function, which was presented in Figs. 4-6. The values of parameters of Weibull distribution functions for narrow particle size fractions were positioned in Table 5 together with the values of R^2 index which indicates that Weibull distribution function approximates well the empirical coordinates of partition curves. Furthermore, it was also noticed that the parameters of Weibull distribution function ρ_o and n have an increasing tendency with growth of particle size in all of the experiments.

TABLE 1

Mass yields of individual size-density fractions of separation products [g], amount of additional water 35 [m^3/h]

Size fraction [mm]	Density fractions [Mg/m^3]																							
	–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			+ 2.0		
	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T
-2.0	781.0	24.0	586.0	66.0	58.0	468.0	20.0	56.0	116.0	12.0	65.0	82.0	8.0	64.0	54.0	3.0	74.0	48.0	4.0	248.0	288.0	5.0	847.0	824.0
2.0-3.15	815.0	31.0	1108.0	48.0	56.0	1200.0	17.0	45.0	194.0	8.0	49.0	102.0	5.0	54.0	94.0	3.0	64.0	72.0	7.0	238.0	384.0	11.0	789.0	1168.0
3.15-5.0	1320.0	52.0	1568.0	71.0	75.0	1914.0	28.0	57.0	236.0	12.0	68.0	134.0	8.0	101.0	116.0	5.0	147.0	114.0	12.0	455.0	440.0	31.0	1463.0	1768.0
5.0-6.3	594.0	21.0	492.0	38.0	24.0	542.0	15.0	19.0	72.0	8.0	28.0	26.0	3.0	43.0	34.0	4.0	81.0	40.0	10.0	242.0	144.0	19.0	864.0	612.0
6.3-8.0	1037.0	26.0	474.0	76.0	29.0	430.0	35.0	15.0	70.0	16.0	46.0	38.0	10.0	59.0	42.0	11.0	122.0	38.0	17.0	473.0	146.0	29.0	1656.0	1026.0
8.0-10.0	1058.0	18.0	166.0	98.0	19.0	206.0	35.0	11.0	20.0	25.0	20.0	10.0	15.0	38.0	18.0	14.0	64.0	12.0	28.0	224.0	66.0	60.0	1684.0	662.0
10.0-12.5	1374.0	14.0	32.0	131.0	9.0	52.0	53.0	7.0	6.0	34.0	13.0	0.0	22.0	13.0	0.0	14.0	40.0	0.0	47.0	171.0	0.0	41.0	1851.0	448.0
12.5-16.0	1852.0	2.0	16.0	198.0	0.0	18.0	107.0	0.0	0.0	59.0	14.0	0.0	43.0	11.0	0.0	31.0	21.0	0.0	96.0	135.0	0.0	47.0	1404.0	526.0
16.0-20.0	1208.0	0.0	0.0	286.0	0.0	0.0	119.0	0.0	0.0	87.0	0.0	0.0	71.0	3.0	0.0	48.0	27.0	0.0	78.0	121.0	0.0	51.0	441.0	516.0
20.0-25.0	2921.0	0.0	0.0	363.0	0.0	0.0	144.0	0.0	0.0	75.0	0.0	0.0	80.0	0.0	0.0	88.0	46.0	0.0	68.0	195.0	0.0	72.0	971.0	514.0

TABLE 2

Mass yields of individual size-density fractions of separation products [g], amount of additional water 50 [m^3/h]

Size fraction [mm]	Density fractions [Mg/m^3]																							
	–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			+ 2.0		
	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T	C	M	T
-2.0	600.0	38.0	632.0	110.0	98.0	460.0	17.0	98.0	282.0	10.0	70.00	170.0	52.0	86.0	160.0	74.0	130.0	110.0	204.0	302.0	340.0	1067.0	946.0	1204.0
2.0-3.15	843.0	34.0	1058.0	142.0	86.0	692.0	16.0	80.0	416.0	9.0	70.00	170.0	58.0	100.0	130.0	69.0	158.0	110.0	244.0	332.0	410.0	908.0	898.0	1502.0
3.15-5.0	1760.0	28.0	1236.0	242.0	56.0	840.0	27.0	66.0	504.0	14.0	88.00	160.0	110.0	146.0	150.0	144.0	264.0	140.0	415.0	616.0	470.0	1566.0	1828.0	2370.0
5.0-6.3	801.0	6.0	342.0	102.0	10.0	320.0	14.0	20.0	112.0	7.0	22.00	50.0	38.0	52.0	50.0	52.0	110.0	50.0	131.0	250.0	150.0	859.0	848.0	1088.0
6.3-8.0	1344.0	10.0	288.0	179.0	18.0	208.0	22.0	22.0	158.0	11.0	32.00	50.0	45.0	64.0	40.0	80.0	162.0	50.0	290.0	576.0	200.0	1599.0	1422.0	1376.0
8.0-10.0	1148.0	4.00	106.0	196.0	12.0	108.0	22.0	14.0	46.00	10.0	24.00	20.0	23.0	34.0	30.0	50.0	124.0	10.0	302.0	596.0	60.0	1785.0	2396.0	1078.0
10.0-12.5	1341.0	4.0	32.0	213.0	12.0	32.0	26.0	18.0	16.0	12.0	0.0	0.0	3.0	18.0	0.0	29.0	68.0	0.0	304.0	680.0	50.0	2601.0	3382.0	460.0
12.5-16.0	1678.0	0.0	4.0	318.0	0.0	10.0	42.0	0.0	0.0	24.0	0.0	0.0	1.0	8.0	0.0	15.0	66.0	0.0	306.0	952.0	40.00	3129.0	4132.0	582.0
16.0-20.0	1545.0	0.0	0.0	258.0	0.0	0.0	44.0	0.0	0.0	36.0	0.0	0.0	7.0	16.0	0.0	11.0	178.0	0.0	340.0	808.0	90.00	2377.0	2554.0	730.0
20.0-25.0	1858.0	0.0	0.0	363.0	0.0	0.0	54.0	0.0	0.0	27.0	0.0	0.0	18.0	0.0	0.0	41.0	200.0	0.0	276.0	1430.0	0.00	1200.0	2098.0	516.0

TABLE 3

Mass yields of individual size-density fractions of separation products [g], amount of additional water 70 [m^3/h]

Size fraction [mm]	Density fractions [Mg/m^3]																							
	–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			+ 2.0		
	C	**M**	**T**	**C**	**M**	**T**	**C**	**M**	**T**	**C**	**M**	**T**	**C**	**M**	**T**	**C**	**M**	**T**	**C**	**M**	**T**	**C**	**M**	**T**
-2.0	759.0	99.0	210.0	159.0	52.0	540.0	14.0	58.0	400.0	3.0	71.0	260.0	3.0	43.0	220.0	1.0	58.0	140.0	1.0	240.0	390.0	2.0	887.0	2330.0
2.0-3.15	976.0	56.0	320.0	165.0	25.0	1030.0	18.0	39.0	510.0	3.0	89.0	320.0	4.0	65.0	290.0	2.0	74.0	190.0	3.0	216.0	450.0	2.0	1005.0	2730.0
3.15-5.0	1710.0	26.0	380.0	269.0	18.0	660.0	28.0	28.0	530.0	8.0	82.0	330.0	8.0	96.0	340.0	5.0	128.0	240.0	4.0	263.0	560.0	2.0	1996.0	4130.0
5.0-6.3	753.0	4.0	150.0	103.0	7.0	240.0	20.0	12.0	130.0	6.0	18.0	100.0	5.0	42.0	90.0	4.0	46.0	70.0	3.0	214.0	180.0	1.0	723.0	1550.0
6.3-8.0	1431.0	9.0	160.0	244.0	3.0	270.0	27.0	9.0	140.0	8.0	16.0	80.0	9.0	48.0	100.0	5.0	66.0	80.0	7.0	280.0	210.0	1.0	1843.0	2420.0
8.0-10.0	1143.0	5.0	50.0	208.0	4.0	100.0	34.0	4.0	40.0	10.0	12.0	30.0	8.0	30.0	50.0	3.0	35.0	30.0	8.0	185.0	70.0	0.0	1161.0	1990.0
10.0-12.5	1350.0	0.0	20.0	295.0	0.0	30.0	45.0	3.0	10.0	11.0	4.0	10.0	14.0	21.0	0.0	5.0	22.0	0.0	5.0	127.0	0.0	5.0	2069.0	1360.0
12.5-16.0	1833.0	0.0	10.0	371.0	3.0	10.0	52.0	7.0	0.0	13.0	0.0	0.0	15.0	13.0	0.0	10.0	31.0	0.0	13.0	167.0	0.0	0.0	1745.0	1960.0
16.0-20.0	1257.0	0.0	0.0	360.0	0.0	20.0	73.0	0.0	0.0	28.0	9.0	0.0	8.0	0.0	0.0	11.0	34.0	0.0	15.0	193.0	0.0	0.0	790.0	2170.0
20.0-25.0	2733.0	0.0	0.0	643.0	0.0	30.0	108.0	0.0	0.0	18.0	0.0	0.0	10.0	0.0	0.0	0.0	45.0	0.0	0.0	317.0	0.0	0.0	894.0	2370.0

C – concentrate, M – middlings, T – tailings

TABLE 4

Yields of separation products

Experiment conditions	Yields [%]		
Amount of additional water [m^3/h]	**Concentrate**	**Middlings**	**Tailings**
35	30.7	30.8	38.4
50	41.0	33.9	25.1
70	25.6	24.9	49.5

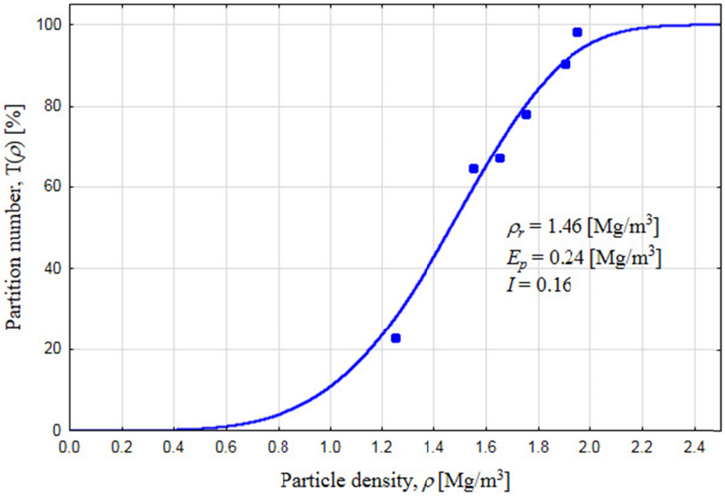

Fig. 1. Partition curve for tailings, amount of additional water 35 [m^3/h], d_o = 1.58 [Mg/m^3], n = 4.75

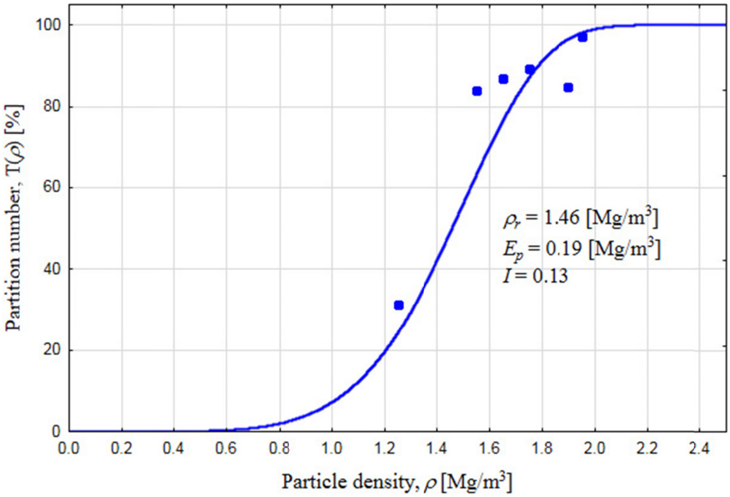

Fig. 2. Partition curve for tailings, amount of additional water 50 [m^3/h], d_o = 1.55 [Mg/m^3], n = 5.94

Table 6 presents the calculated separation precision factors in narrow particle fractions for each of the experiments. It was noticed that the separation density lowers with increasing particle size while probable error and imperfection have a tendency to decrease. The separation density for particles smaller than 6.3 [mm] is close to the density of water in the case of additional water amount equal to 35 [m^3/h], which is also visible in Fig. 4. It means that these small particles did not achieve equilibrium layers and they circulate in upper layers of jig bed.

The calculated values of probable error in each particle size fraction allowed to plot relation of separation precision measured by probable error and particle size, which was shown in Fig. 7.

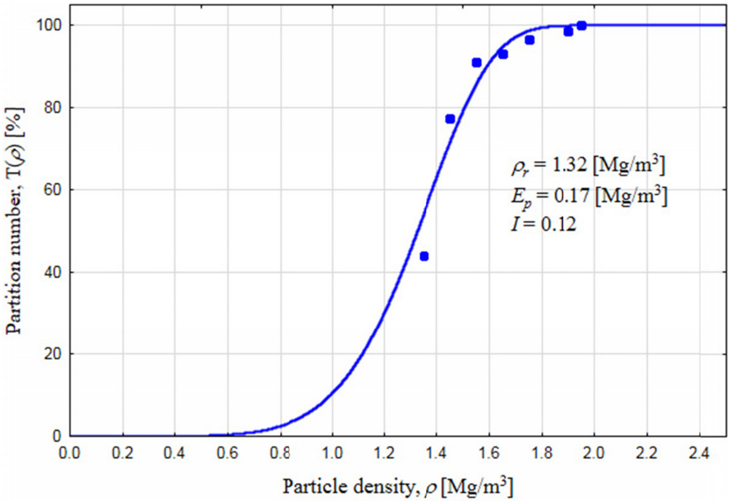

Fig. 3. Partition curve for tailings, amount of additional water 70 [m^3/h], d_o = 1.40 [Mg/m^3], n = 6.58

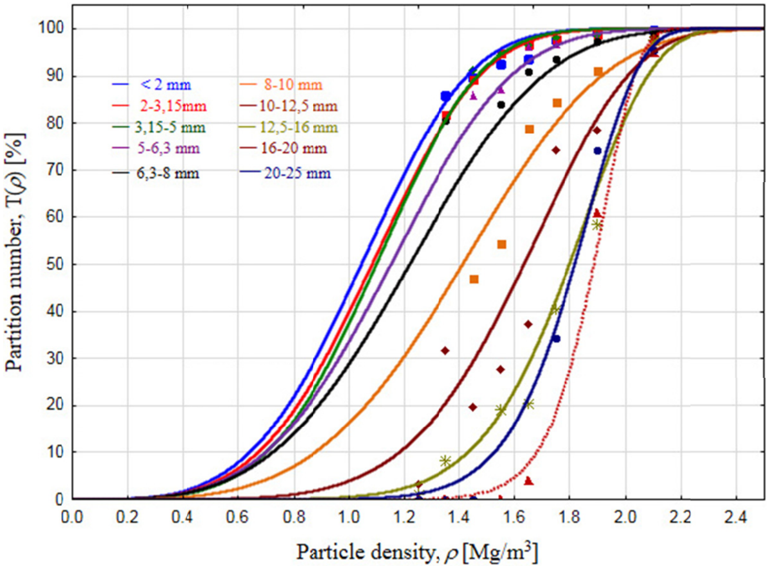

Fig. 4. Partition curves for tailings according to particle fractions, amount of additional water 35 m^3/h

For empirical points the trend lines illustrating analyzed relations were added. It can be noticed that with the growth of particle size the separation precision lowers for the amounts of additional water equal to 35 and 50 [m^3/h], while for the amount of 70 [m^3/h] the value of probable error stays more or less on the same level equal to 0.12-0.13 [Mg/m^3].

Analyzing the value of imperfection in separated narrow particle size fractions is possible to notice that this factor's value decreases with growth of the amount of additional water but only for the fractions being smaller than 5.0 mm. For fractions bigger than 5.0 mm the separation preciseness is the biggest by medium amount of additional water which is 50 [m^3/h]. However, it should be noticed that for particles bigger than 12.5 mm the imperfection value achieves the values below 0.1. Because of this, the hydrodynamic conditions of the process are crucial in

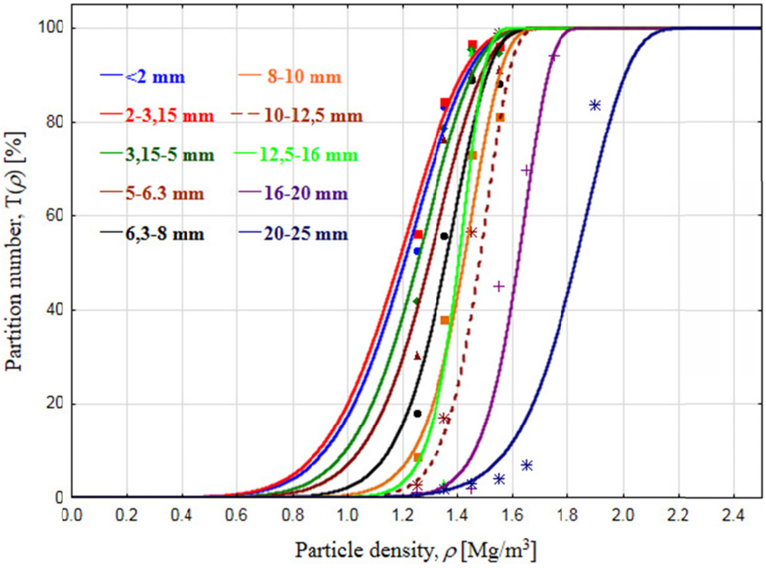

Fig. 5. Partition curves for tailings according to particle fractions, amount of additional water 50 m^3/h

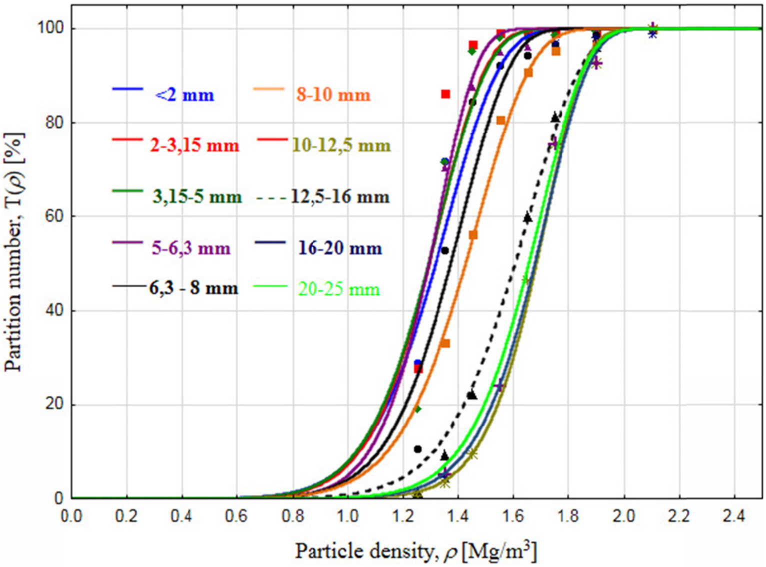

Fig. 6. Partition curves for tailings according to particle fractions, amount of additional water 75 m^3/h

case of separation of fine particles. Having the purpose of obtaining possibly most precise coal fines beneficiation, the possibility of separation and separately beneficiation of fine and coarse particles within the range of granulation being directed to the process should be taken into consideration. In such conditions better results of separation will be obtained by selecting fine assortments. However, the quality of the beneficiation products should be taken into consideration because of their useful component contents (as, for example, calorific value, elementary carbon contents) in separated concentrates and not useful components contents in tailings (ash contents, sulfur contents).

TABLE 5

Parameter values of Weibull distribution functions

Size fraction [mm]	**Amount of additional water [m^3/h]**								
	30			**50**			**75**		
	d_o	n	R^2	d_o	n	R^2	d_o	n	R^2
0-25	1.54	3.75	0.95	1.55	5.94	0.95	1.40	5.78	0.95
0-2.0	1.15	3.84	0.99	1.27	6.95	0.97	1.38	7.91	0.96
2.0-3.15	1.19	3.92	0.95	1.25	6.74	0.96	1.35	10.71	0.96
3.15-5.0	1.20	4.17	0.96	1.31	8.14	0.97	1.35	8.36	0.97
5.0-6.3	1.27	3.75	0.96	1.35	8.76	0.98	1.34	7.23	0.96
6.3-8.0	1.35	3.60	0.95	1.40	11.43	0.95	1.43	8.92	0.99
8.0-10.0	1.55	3.95	0.96	1.46	13.74	0.96	1.49	8.45	0.99
10.0-12.5	1.74	5.81	0.98	1.51	17.44	0.95	1.67	9.23	0.97
12.5-16.0	1.88	8.25	0.97	1.43	19.46	0.99	1.73	13.04	0.97
16.0-20.0	1.93	16.13	0.99	1.65	18.6	0.98	1.73	11.67	0.99
20.0-25.0	1.88	10.8	0.98	1.88	12.8	0.97	1.71	11.09	0.99

TABLE 6

Values of separation precision factors

Separation precision factors	**Particle size [mm]**									
	0-2.0	**2.0-3.15**	**3.15-5.0**	**5.0-6.3**	**6.3-8.0**	**8.0-10.0**	**10.0-12.5**	**12.5-16.0**	**16.0-20.0**	**20.0-25.0**
Additional water 35 [m^3/h]										
ρ_{50}, **[Mg/m^3]**	1.02	1.07	1.09	1.15	1.22	1.41	1.63	1.80	1.89	1.82
E_p, **[Mg/m^3]**	0.25	0.24	0.21	0.24	0.26	0.28	0.22	0.17	0.09	0.13
I **[/]**	0.25	0.22	0.19	0.21	0.21	0.20	0.13	0.09	0.05	0.07
Additional water 50[m^3/h]										
ρ_{50}, **[Mg/m^3]**	1.20	1.18	1.25	1.29	1.36	1.42	1.48	1.40	1.62	1.83
E_p, **[Mg/m^3]**	0.13	0.14	0.12	0.12	0.09	0.08	0.07	0.06	0.07	0.11
I **[/]**	0.11	0.12	0.10	0.09	0.07	0.06	0.04	0.04	0.04	0.06
Additional water 75 [m^3/h]										
ρ_{50}, **[Mg/m^3]**	1.32	1.30	1.29	1.27	1.37	1.43	1.60	1.68	1.68	1.65
E_p, **[Mg/m^3]**	0.13	0.10	0.12	0.14	0.12	0.13	0.14	0.10	0.11	0.12
I **[/]**	0.10	0.07	0.09	0.11	0.09	0.09	0.08	0.06	0.07	0.07

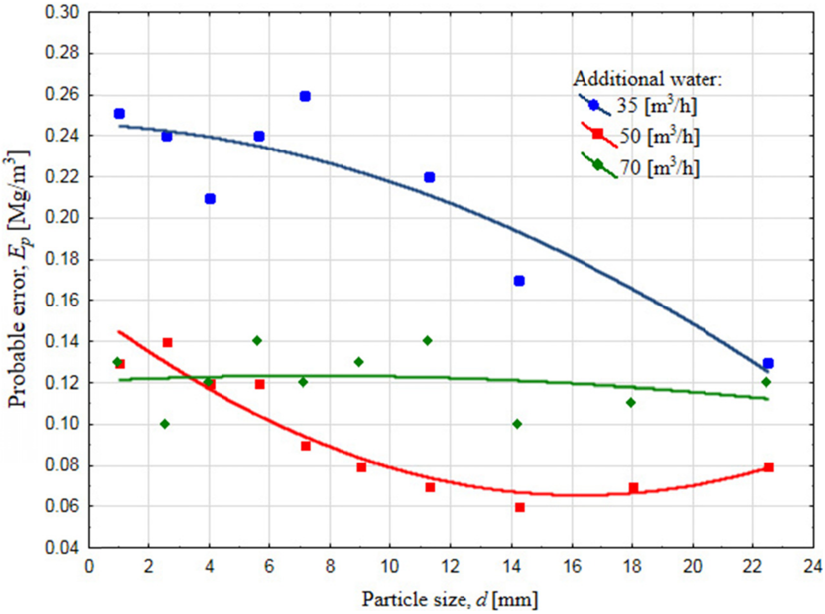

Fig. 7. Relation of probable error and particle size

6. Conclusions

The analysis of elaborated results of sampling the node of beneficiation of steam coal fines in jig allows for precise conclusions concerning the separation precision process in changeable hydrodynamic conditions of the process. To evaluate beneficiation effects, the separation precision factors, which were calculated on the basis of approximated partition curves, were used mainly by means of probable error and the influence of particle size change on jigging effects was shown. The probable error E_p determines the critical density which can be exceeded, and not exceeded by individual particles with the same probability by scatter of elementary fraction of certain density. On the basis of conducted industrial experiment and performed calculations, it was stated that empirical partition curves can be successfully approximated by means of Weibull distribution function used as a basis of the calculation of the separation precision factors. The shape of partition curves shown in Figs. 1-3 as well the calculated values of separation precision for tailings separated from wide particle fraction of coal fines directed to jigging process (the feed) illustrates that the biggest precision of separation was achieved for the case where an amount of additional water was equal to 70 [m^3/h]. The analysis of separation precision in narrow particle fractions allowed to notice that in the case of fine particles, smaller than 6 mm, the precision of separation is lower than in the case of coarse particles, especially for the case where the amount of additional water was equal to 35 [m^3/h]. This is to small an amount of water in working bed of the jig to ensure sufficient liberation of particles according to their geometrical properties and density (Brożek & Surowiak, 2004; 2005; Surowiak, 2014; Surowiak & Brożek 2016) by flow intensity of the feed directed to jigging equal to 300 [Mg/h]. It causes that particles do not occur in their equilibrium layers and finally do not occur in appropriate products.

The conducted analysis of influence of particle size on preciseness of separation indicated that there is a significant relation between particle size distribution and conditions of motion of a jig which influence on separation effects in case of narrow particle size fractions as well as in case of the feed being directed to the device (Heyduk & Pielot, 2014). The analysis of the separation preciseness for narrow fine particle fractions showed that the biggest scatter of these particles, so lower separation preciseness, is related to separation of fine particles <6 mm from the whole range of granulation. For these particles the hydrodynamic conditions of jig work have bigger influence which are related to the amount of additional water. For the particles bigger than 12.5 mm the amount of additional water does not have such big influence, but the partition density grows significantly for fractions bigger than 12.5 mm.

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