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ABATEMENT OF SULPHUR DIOXIDE EMISSION BY DECREASING THE CONTENT OF PYRITE SULPHUR IN BITUMINOUS COAL

The objective was to study the electrostatic separation method as a process that is applicable to the enrichment of bituminous coal and to consider the related environmental aspects. The experiments were conducted in a double-drum separator and involved one-stage or multi-stage processes. The experimental results show that the efficiency of the separation process is influenced by three fundamental factors: the grain diameter, the voltage applied, and the type of the conditioning plate.

The electrostatic separation method considered from the viewpoint of environment protection is favourable in that the burning of low-sulphur bituminous coal — especially in the boilers of power plants — brings about a substantial abatement of sulphur dioxide emissions, thus contributing to a decrease of environmental pollution.

1. INTRODUCTION

The recent dynamic development of industry in Poland has brought about a considerable increase of energy demand and, consequently, of atmospheric emissions which account for the ever imminent threats of irreversible environmental damage. Within the last decade air pollution has become a serious problem not only in large cities, but also in many small towns. Most of the air pollution results from fuel combustion. Combustion processes contribute to increased emissions of both organic and inorganic sulphur compounds which belong to the main class of primary air pollutants.

In Poland, the basic fuel used for power generation is bituminous coal with an average sulphur content amounting to 1.5%, most of which comes from pyrite. In some instances, pyrite sulphur contained in the fuel accounts for

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as much as 2–5 %. Thus, if 1 MW of power is generated from 2 % and 5 % pyrite sulphur coals, the emission of sulphur dioxide amounts to about 14 kg/h and 35 kg/h, respectively. Despite these alarming quantities, it cannot be expected that the output of high-sulphur-content coal will be reduced in the nearest future.

To abate the emmission of sulphur dioxide either the fuel burnt or the flue gas produced should be desulphurized. Desulphurization of flue gases requires the usage of expensive treatment devices which increase by about 20 % the total cost of power generation.

Having all these in mind, the investigations on the desulphurization of bituminous coal were initiated. The main objective of this study was to obtain high-quality and low-pyrite-sulphur concentrates from bituminous coal.

2. EXPERIMENTAL

2.1. METHOD

The experiments involved the electrostatic separation method, based on the difference in the electric resistance of the components of the separated mixture. A selective electrification of the grains of components enables their separation in the electric field.

2.2. ELECTROSTATIC SEPARATOR: DESIGN AND PRINCIPLES OF OPERATION

The separation process was carried out in an electrostatic double-drum separator (fig. 1). The material under test was placed in a container *1* and sent to a vibrating plate *3* through an indentated roll feeder *2*. The 10^0 inclination of plate was kept constant throughout the experimental run. Vibration was generated by an electromagnetic vibrator *4*. From the vibrating plate *3* the experimental material was sent to a rotating earthed electrode *5* by means of another roll feeder *6* to ensure a uniform distribution of the material on the electrode surface. Electrode *7* was connected with the high-voltage source. The receiver *8* of the separated components consisted of movable baffle plates and was placed in the bottom part of the separator. The electrostatic separator was situated in a chamber in order to ensure the measuring conditions required.

2.3. EXPERIMENTAL MATERIAL AND VARIABLE PROCESS PARAMETERS

The coals under test were taken from Polish bituminous coal mines. Their grain size varied from 0 to 20 mm. The results of sieve analysis and the sulphur contents for each grain fraction are given in tab. 1. Two conditioning plates, one made of metal, the other of methyl polymethacrylate, were used in the experiments. The separation process involved the grain fractions: 0.6, 0.43, 0.3, 0.2, and 0.102 mm, and a mixture of all the fractions. The applied voltages were 15 kV, 25 kV, and 35 kV.

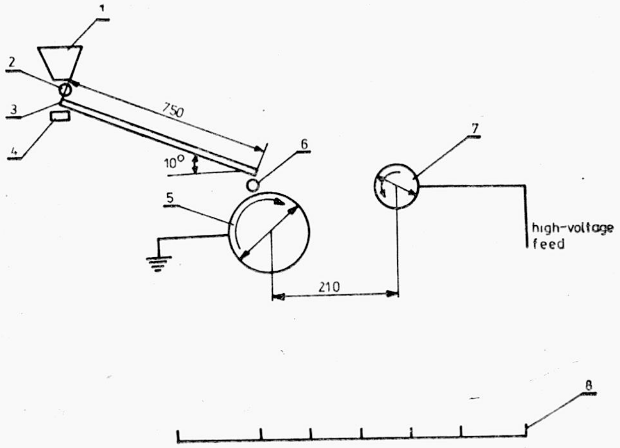

Fig. 1. Electrostatic separator

1 – container; *2, 6* – roll feeders; *3* – vibrating plate; *4* – electromagnetic vibrator; *5* – earthed electrode *7* – voltage electrode; *8* – receiver

Rys. 1. Schemat blokowy separatora elektrostatycznego

1 – zasobnik; *2, 6* – dozowniki; *3* – wibrująca płyta; *4* – wibrator elektromagnetyczny; *5* – elektroda uziemiona; *7* – elektroda napięciowa; *8* – odbieralnik

Table 1

Results of sieve analysis of bituminous coal and sulphur content in the individual grain fractions

Analiza sitowa węgla kamiennego oraz zawartość siarki w poszczególnych klasach ziarnowych

Grain fractions	Mass fraction	Total amount	Sulphur content		
			Sulphate sulphur	Pyrite sulphur	Total sulphur
mm	%	%	%		
1.02–0.6	25.0	25.0	0.11	1.72	1.83
0.6–0.43	24.5	49.0	0.12	1.83	1.95
0.43–0.3	7.8	57.3	0.10	1.90	2.00
0.3–0.2	12.2	69.5	0.09	2.30	2.39
0.2–0.102	14.8	84.3	0.14	2.40	2.54
0.102–0.00	15.7	100.0	0.16	2.58	2.74

3. DISCUSSION OF RESULTS

The experimental results made it possible to determine the optimum parameters for the coal enrichment process. The process is effective, when the mass fraction of the concentrate (i.e. the enriched portion of coal) is high, and the percentage of sulphur in the concentrate is relatively low.

The most effective voltages were 15 kV and 25 kV. While 15 kV yielded greater quantities of lower-quality concentrate, 25 kV gave smaller quantities of low-sulphur concentrate. The results obtained at the most advantageous voltages are listed in tab. 2. The mass fraction of the concentrate varies from one grain size to another. The highest percent 90.6 was obtained for the 0.2 mm fraction, the percent of sulphur being 1.3. This does not mean, however, that a high mass fraction of the concentrate is accompanied by a low sulphur content. For the 0.43 mm fraction, for instance, the sulphur content in the concentrate is low and amounts to 0.15 %, the mass fraction of the concentrate being 56.4 % only.

The influence of the voltage applied on the separation degree was studied for all the fractions under test. As it has already been mentioned, the highest efficiencies were achieved at 15 kV and 25 kV.

Table 2

Separation efficiencies for individual fractions at optimum voltages
Zestawienie wyników rozdziału węgla kamiennego dla poszczególnych frakcji przy najkorzystniejszych napięciach

Fraction mm	Voltage kV	$S_w^{(1)}$ %	Concentrate				Waste product			K_s^9
			$U_{m_k}^{(2)}$ %	$S_k^{(3)}$ %	$A_k^{(4)}$	$C_s^{(5)}$ %	$U_{m_0}^{(6)}$ %	$S_0^{(7)}$ %	$A_0^{(8)}$	
0.6	35.0	1.72	70.3	0.27	6.37	447.8	29.7	5.19	0.33	45.7
0.43	25.0	1.84	56.4	0.15	12.27	692.0	43.6	4.0	0.46	34.5
0.3	25.0	1.90	51.6	0.18	10.6	546.9	48.4	3.8	0.5	22.6
0.2	15.0	2.30	90.6	1.3	1.77	160.4	9.4	11.6	0.19	89.8
0.102	15.0	2.40	65.8	0.76	3.16	207.9	34.2	5.53	0.43	14.4

(1) Pyrite sulphur content in the original sample.
(2) Mass fraction of the concentrate.
(3) Pyrite sulphur content in the concentrate.
(4) Degree of pyrite sulphur removal ($A_k = S_w/S_k > 1$).
(5) Enrichment coefficient of the concentrate ($C_s = A_k \times U_{m_k}$).
(6) Mass fraction of the waste product.
(7) Pyrite sulphur content in the waste product.
(8) Degree of pyrite sulphur enrichment in the waste product ($A_0 = S_w/S_0 < 1$).
(9) Coal enrichment coefficient ($K_S = (A_k \times U_{m_k})/(A_0 \times U_{m_0})$).

Table 3 gives the results obtained with the two types of the conditioning plates for the 0.2 mm fraction. As shown by these data (as well as by the behaviour of the coal enrichment coefficient K_s), the metal plate is more effective than that made of methyl polymethacrylate. This might be due to the less selective electrification of the grains moving down the plastic plate. Getting in touch with a plastic material, they are made subject to an increased electrification which slows down their sliding.

Table 3

Relationship between the degree of separation and the type of conditioning plates (0.2 mm fraction)*

Wpływ płyty kondycjonującej na rozdział węgla kamiennego (frakcja 0.2 mm)
$S_{c_w} = 2.39\%$, $S_w = 2.3\%$

Voltage	Concentrate			Waste product				K_s	Conditioning plate
kV	U_{m_k} %	S_k %	A_k	C_s %	U_{m_0} %	S_0 %	A_0		
15.0	82.6	1.23	1.87	154.5	17.4	7.66	0.3	29.6	plastic material
	90.6	1.3	1.77	160.4	9.4	11.9	0.19	89.8	metal
25.0	64.3	1.84	1.25	80.4	35.4	3.3	0.7	3.22	plastic material
	85.5	1.62	1.42	121.4	14.5	6.3	0.37	22.6	metal

* For the notations of the symbols used see tab. 2.

The most advantageous fractions are those ranging between 0.102 and 0.6 mm. Grains of 0.075 mm show a tendency to adhere to the surface of the roll due to the action of adhesive forces.

A disadvantageous phenomenon accounting for a complete inhibition of the separation process is the pulverization of very fine fractions inside the chamber of the electrostatic separator. Thus, the investigations did not include grain fractions greater than 0.6 mm because of electric arcs that were generated by the voltages yielding an effective separation process.

The investigations also show that the voltage applied must be increased with the increasing grain size (tab. 2). Hence, for the 0.102 mm fraction, the voltage amounts to 15 kV, that for the 0.6 fraction being 35 kV.

The results obtained in a one-stage process were the starting point to the study of multi-stage enrichment process and to find out what is the influence of surface-active substances on the desulphurization of coal. Figure 2 shows the diagram of a multi-stage enrichment process (fraction 0.3 mm, voltage 25 kV, conditioning plate made of metal). Table 4 gives the results a of multi-stage enrichment process. Results obtained in one-stage and multi-stage processes are presented in tab. 5.

In the multi-stage process the mass fraction of the concentrate increased by 10%, and the pyrite sulphur content decreased from 0.6 to 0.3%. Sulphur

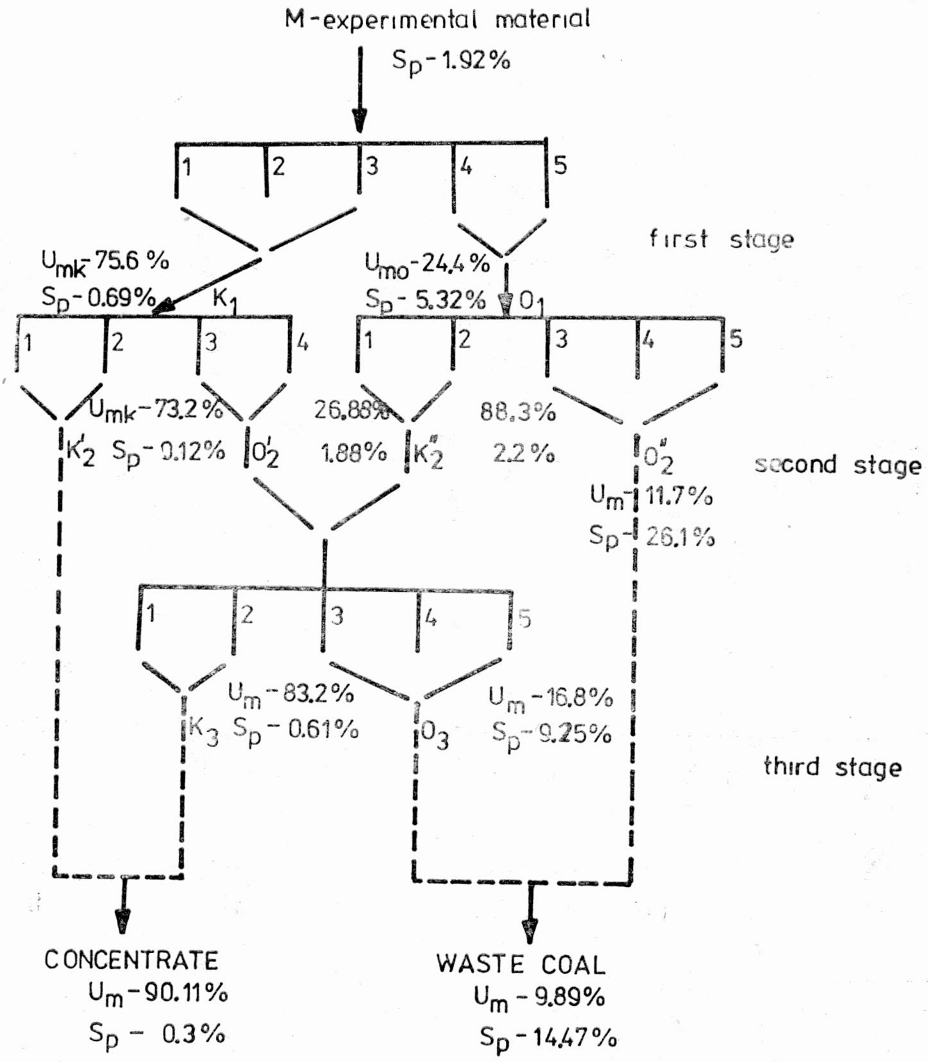

Fig. 2. Multi-stage process of bituminous coal enrichment

coal fraction — 0.3 mm; voltage — 25 kV; conditioning plate made of metal; *1–5* — baffle plates

Rys. 2. Schemat wielostopniowego wzbogacania węgla kamiennego

frakcja 0,3 mm; napięcie 25 kV; płyta metalowa; *1–5* — przegrody

Table 4

Multi-stage enrichment of bituminous coal (fraction, 0,3 mm; voltage, 25 kV; metal plate)
Wielostopniowe wzbogacanie węgla kamiennego (frakcja 0.3 mm; napięcie, 25 kV; płyta metalowa

Separation product	Voltage kV	S_{c_w}* %	S_w %	U_m %	S %	A	C_s %	K_s	Stage
K_1		2.03	1.92	75.6	0.6	3.2	241.9	27.5	first stage
O_1				24.4	5.32	0.36	—		
K_2				73.2	0.12	16.0	1171.2		
O_2				26.8	1.88	1.02	—		
K_2	25.0	2.03	1.92	88.3	2.2	0.87	76.8	42.84	second stage
O_2				11.7	26.1	0.076	—		
K_3		2.03	1.92	88.2	0.61	3.15	262.1	74.3	third stage
				16.8	9.25	0.21	—		
K		20.3	1.92	90.11	0.3	6.4	576.7	416.3	end effect
				9.89	14.47	0.14	—		

* Total sulphur in the initial sample. For other notations of the symbols used see tab. 2.

Table 5

Separation in single-stage and multi-stage processes (0.3 mm fraction; metal plate; $S_{p_w} = 1.9$ to 1.92%)*
Zestawienie wyników badań rozdziału węgla kamiennego w procesie jedno- i wielostopniowym (frakcja 0,3 mm, płyta metalowa, $S_{p_w} = 1{,}9$ do 1,92%)

Process	Voltage kV	Concentrate				Waste product			K_s
		U_{m_k} %	S_{p_k} %	A_k	C_s %	U_{m_0} %	S_{p_0} %	A_o	
single-stage process	15.0	79.3	0.56	3.39	268.8	20.7	7.0	0.27	48.1
multi-stage process	15.0	90.11	0.3	6.4	576.7	9.89	14.5	0.14	416.5

* For the notations of the symbols used see tab. 2.

content in the waste product increased from 7 to 14 %. These effects are additionally substantiated by the behaviour of coefficient K_s. The multi-stage enrichment of a mixture of fractions brought about a 10 % increase in the mass-fraction of the concentrate and an almost 0.3 % decrease in sulphur concentration.

To determine the influence of surfactants on the separation process, the coal grains were conditioned with nonylopotassium xanthate. The investigations involved 0.6 mm and 0.3 mm fractions and a mixture of both. The results are listed in tab. 6. As shown by these data, conditioning with nonylopotassium xanthate yields only a slight improvement of the separation effect. The mass fraction of the concentrate increased by 3 %, and sulphur content in the concentrate decreased by 0.2 %.

Table 6

Relationship between the degree of separation and the presence of surfactants (fractions 0.6 mm, 0.3 mm and mixture of both; metal plate)*

Wpływ substancji powierzchniowo czynnych na rozdział węgla (frakcja 0,6 mm, 0,3 mm i mieszanina frakcji; płyta metalowa)

Fraction mm	Voltage kV	S_w %	Concentrate				Waste product			K	Material
			U_{m_k} %	S_k %	A_k	C_s %	U_{m_0} %	S_0 %	A_0		
0.6	25.0	1.75	85.1	0.58	3.02	257.0	14.9	8.34	0.21	82.1	conditioned
		1.72	82.6	0.80	2.15	177.6	17.4	5.60	0.30	34.0	not conditioned
0.3	15.0	1.94	84.1	0.39	4.97	418.0	15.9	10.1	0.19	138.3	conditioned
		1.90	79.3	0.56	3.39	268.8	20.7	7.0	0.27	48.1	not conditioned
mixture of both fractions	25.0	2.00	75.4	0.72	2.78	209.6	24.6	6.1	0.33	25.8	conditioned
		2.08	72.3	0.96	2.17	156.9	27.7	4.6	0.45	12.6	not conditioned

* For the notations of the symbols used see tab. 2.

4. SUMMARIZING COMMENTS

The efficiency of the electrostatic separation process depends on the following technological parameters: grain size, voltage and type of the conditioning plate. They exert a direct effect not only on the charging and discharging mechanisms, but also on the trajectory of the separated grains after they have left the earthed electrode. It was found that there were some optimal voltages at which the electrostatic separation was the most effective. The grain size range in which the efficiency of enrichment process in an electric field was very high has been also determined. The greatest grain size tested amounted to 0.6 mm. Electric arcs generated by high voltages which are required for the separation of grains greater than 0.6 mm did not permit their application. The minimum grain size, below which no separation occurs, amounts to 0.102 mm. Grain fractions smaller than 0.102 mm should therefore be eliminated.

The most advantageous degree of enrichment was achieved with a metal plate at a voltage of 15 kV and 25 kV.

The investigations show that good separation effects can also be obtained in a one-stage process. The efficiency η of the method proposed is 70%. The efficiency of a three-stage enrichment amounts to 85%. This means that electrostatic separation may be of importance in coal desulphurization and, consequently, in the abatement of sulphur dioxide emissions.

The waste product obtained in the separation process amounts to some 20%. It contains considerable quantities of pyrite sulphur (up to 15%) and ash (up to 50%) and cannot be used as fuel.

There are two ways of utilizing these wastes:

1. They may be combusted, provided that highly efficient devices for the dedusting and desulphurization of flue gases are available. Fly ash may be the source of ferric oxide (magnetite) recovery by magnetic separation. The recovered material can be used in metallurgical processes. The end product of flue gas desulphurization is sulphuric acid having a variety of applications. The method suggested here ensures a complete utilization of wastes with almost no nuisance to the environment. However, this no-waste technology still requires both engineering and economic considerations.

2. The waste material has a high sulphur content and may therefore be utilized in some other technologies, such as the combined production of Portland clinker and sulphuric acid from anhydrite. High-sulphur waste coal is of utility for the reduction of calcium sulphate. In this way, the concentration of sulphur dioxide in the gas used for sulphuric acid synthesis will be increased. The procedure suggested here requires modification of the available technology.

Further investigations on the desulphurization of bituminous coal should involve fractions below 0.1 mm. For this purpose it would be advisable to use electrostatically aided cyclone separators. There is no need to modify the electrostatic separator so that it would be able to separate grains greater than 0.6 mm. This is because pyrite sulphur is included predominantly in fine grains, and the characteristic of the coal burnt in power plants has revealed that 40% of the fuel consists of grain fractions which range from 0 to 1 mm.

5. CONCLUSIONS

1. Electrostatic separation is an efficient method of enrichment which may be successfully employed for the desulphurization of coal, contributing to a substantial abatement of sulphur dioxide emissions.

2. Bituminous coal is efficiently enriched in a one-stage process, but the degree of enrichment may be increased when a three-stage process is involved.

3. The method of electrostatic separation can also be employed in the enrichment of other raw materials.

OGRANICZENIE EMISJI DWUTLENKU SIARKI PRZEZ ZMNIEJSZENIE ZAWARTOŚCI SIARKI PIRYTOWEJ W WĘGLU OPAŁOWYM

Celem badań było sprawdzenie, czy w ochronie środowiska można stosować rozdział ziarnistej mieszaniny węgla kamiennego w elektrostatycznym separatorze dwubębnowym. Parametrami zmiennymi były napięcie oraz wielkość ziarn i płyty kondycjonującej. Badania prowadzono jedno- i wielostopniowo. Stwierdzono, że separacja elektrostatyczna jest skuteczną metodą wzbogacania węgla kamiennego.

BESCHRÄNKUNG DER SCHWEFELDIOXIDEMISSION DURCH VERMINDERUNG DES PYRITSCHWEFELGEHALTES IN DER HAUSBRANDKOHLE

Der Ziel der Untersuchungen ist die Prüfung, ob es in der Umweltschutztechnik möglich ist, eine Verteilung des körnigen Steinkohlegemisches im elektrostatischen Doppeltrommelabscheider durchzuführen. Die variablen Parameter sind: die Stromspannung, sowie Korngröße und die Größe der Konditionierungsplatte. Die Untersuchungen werden in Einund Mehrstufensystemen durchgeführt. Es wird festgestellt, daß die elektrostatische Abscheidung eine wirksame Steinkohleanreicherungsmethode darstellt.

ОГРАНИЧЕНИЕ ЭМИССИИ ДВУОКИСИ СЕРЫ ПУТЁМ УМЕНЬШЕНИЯ СОДЕРЖАНИЯ ПИРИТНОЙ СЕРЫ В ПЕЧНОМ АНТРАЦИТЕ

Целью исследований была проверка, можно ли, в охране среды, применять разделение гранулярной смеси каменного угля в электростатическом двухбарабанном сепараторе. Переменными параметрами были напряжение, а также величина зёрен и кондиционирующей плиты. Исследования проводились одно- и многоступенчатым методом. Установлено, что электростатическая сепарация является эффективным методом обогащения каменного угля.