

THE APPLICATION OF SUPERCONDUCTING MAGNET SYSTEMS TO DRY MAGNETIC SEPARATION OF COAL

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Abstract Two laboratory-scale facilities for dry magnetic separation using superconducting magnet systems are described. The results of magnetic separation of pulverized coal samples from various open-cast mines in Czechoslovakia, using these facilities, are presented. The efficiency of both open-gradient and high-gradient magnetic separation techniques, together with pretreatment of coal samples, are discussed.

INTRODUCTION

The most frequent way of utilization of pulverized brown coal is its combustion in boilers for powder firing at thermal power plants. Consequently, considerable quantity of sulphur dioxide is emitted into the atmosphere (in addition to other undesirable gaseous pollutants, e.g. oxides of arsenic and fluorine). Serious ecological problem caused by acid rain thus arises. Apart from chemical methods of removing sulphur dioxide from combustion gases, alternative methods have been investigated, with the main goal to reduce the sulphur content in the coal matter prior to combustion. Magnetic separation is one of these physical methods.

Steam coal contains, in general, 1 to 5 per cent of sulphur, of which two thirds are bonded mostly in pyrite and marcasite. Magnetic properties of these minerals differ from those of pure coal matter which indicates a possibility of applying magnetic separation techniques. Taking into account the processing of brown coal prior to its combustion in boilers for powder firing where the feed is

simultaneously milled and dried in circulating pulverizers, only dry beneficiation process is acceptable.

Reports [1, 2] in which high-gradient magnetic separation (HGMS) was applied to unclassified coal, showed that the results of separation had been poor. Other authors [3, 4, 5, 6], however, showed that HGMS, as well as open-gradient magnetic separation (OGMS), can be successfully used as inexpensive and efficient technique for reducing not only the content of pyritic sulphur but even some accompanying inorganic minerals that form ash.

These impurities reduce the calorific value of the coal and, at the same time, cause a higher wear of milling equipment and of furnaces. For magnetic separation to be successful, pretreatment of the feed is necessary. Particularly important is the requirement of selectivity of milling whereby the mineral components are liberated from the coal matter. It is also inevitable to dry and dedust the finest fractions of particles. Due to moisture and/or mutual electrostatic interactions, fine particles tend to agglomerate.

Design of a superconducting open-gradient magnetic separator has several advantages compared with a high-gradient magnetic separator. First of all, problems associated with matrix clogging are eliminated. Similarly, problems with "dead time" and/or replacement of the matrix are absent, too. On the other hand, the efficiency of HGMS can be greater than that of OGMS, particularly as a result of higher magnetic forces generated on the surface of matrix elements.

The aim of this contribution is to demonstrate the viability of both techniques and to compare their efficiencies from the point of view of beneficiation parameters (grade, recovery) for three different samples of coal. The importance of pretreatment of coal prior to magnetic separation will also be discussed.

EXPERIMENTAL SET-UP

High-Gradient Magnetic Separation

HGMS experiments were performed using a superconducting magnet system developed at the Institute of Electrical Engineering, Slovak Academy of Sciences in Bratislava. The system was originally designed for high-temperature plasma heating experiments [7].

The magnet system consisting of two identical axisymmetric coils wound with multifilamentary Nb-Ti superconductor (dia. 1 mm) is located in a cryostat with warm bore of 140 mm in diameter (Fig. 1). In the working space, where the magnetic induction of up to 5 T can be generated, a brass chamber with

rectangular cross section (50 x 40 mm) and height of 150 mm is placed. The chamber contains a matrix consisting of ferromagnetic stainless steel rods 3 mm in diameter, the distance between the rods being 1.5 mm. Each matrix element is arranged perpendicularly to the direction of the vector of the magnetic induction.

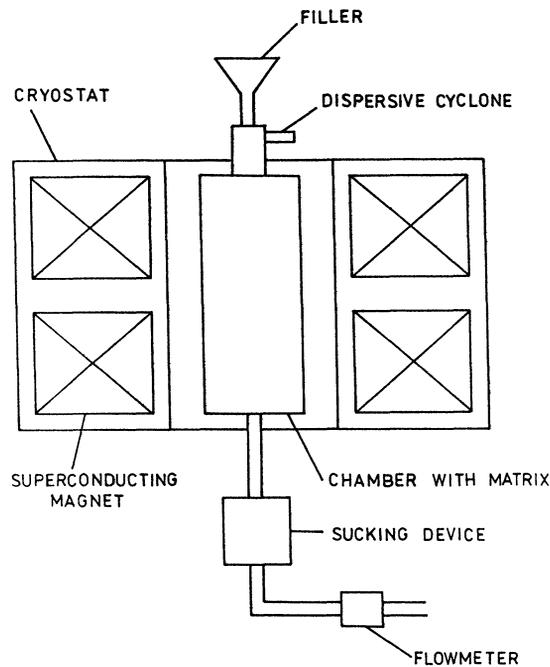


FIGURE 1 Schematic view of the HGMS experimental facility.

A hopper feeder together with a dispersing cyclone situated on top of the chamber have been used to provide a quasi-homogeneous mixture of pulverized coal and air. The bottom part of the chamber is connected to a suction device that enables to measure the volume of sucked air. While the magnetic field was switched on, the volume of sucked air was adjusted by the control of revolutions of the suction device. A well-defined quantity of pulverized coal was then introduced into the funnel. Particles that are not affected by the magnetic force field of the matrix are collected in a bag in the suction device. Magnetic particles can be removed from the surface of the matrix elements after switching the magnetic field off by applying the suction at the maximum rate.

Open-Gradient Magnetic Separation

All OGMS experiments were performed with a superconducting open-gradient magnetic separator. The magnet system consisting of four coaxial coils energized opposite directions, wound with 0.5 mm monofilamentary Nb-Ti wire with 1:1 copper to superconductor ratio, is located in a cryostat with the warm bore of 90 mm in diameter (Fig. 2).

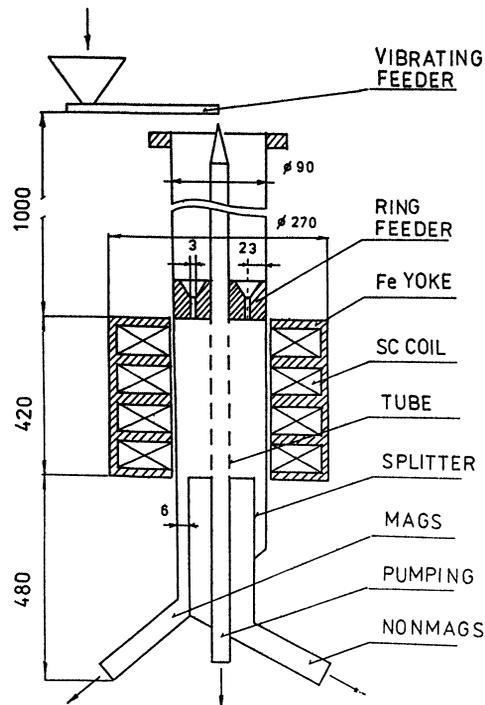


FIGURE 2 Geometry of the superconducting open-gradient magnetic separator

The inner diameter of the coils is 126 mm, the outer diameter varies between 177 mm to 190 mm. Distance between the coils is 20 mm and the overall length of the magnet is 420 mm. The central tube of the coil former is made of non-magnetic stainless steel. The entire winding is located in a ferromagnetic yoke.

It can be shown that in a given geometry, and for the magnetic field up to 2 T, the ferromagnetic yoke increases the magnetic force by about 30 per cent compared to the arrangement when the yoke is not used.

The deflecting component of the radial magnetic force density, as a function of distance z in axial direction 5 mm from the surface of the cryostat wall is shown in Fig. 3.

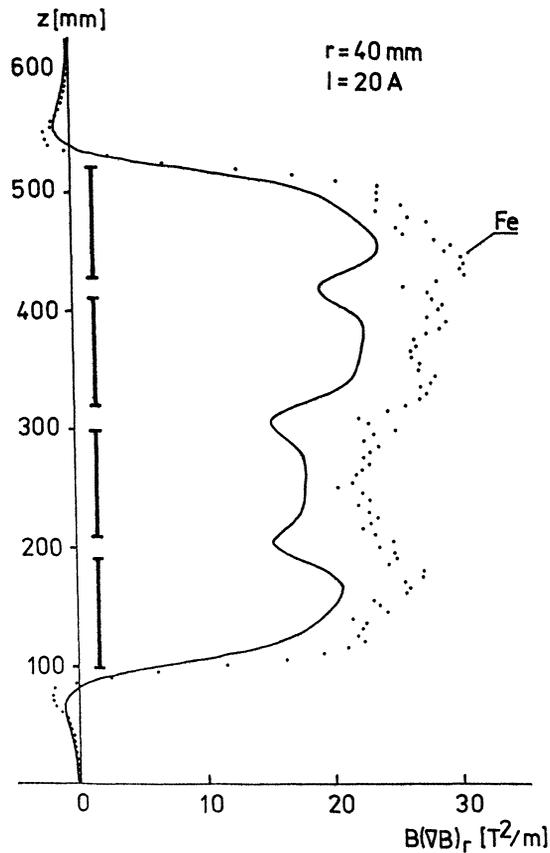


FIGURE 3 Influence of iron yoke on axial dependence of the radial magnetic force density component in the OGMS channel.

The curve represents the dependence as calculated for the magnet without the iron yoke. Points in Fig. 3 corresponding to the actual magnet with iron yoke were obtained by computer processing of the known distribution of the magnetic field measured with the help of Hall-effect probes. In both cases the current in the magnet was 20 A. Critical current in the magnet was 38 A which corresponds to the component of the maximum radial force density of up to $110 \text{ T}^2/\text{m}$.

CHARACTERISTICS OF INVESTIGATED COAL SAMPLES

Samples of brown coal from three open-cast mines (Obrancu miru - designed as A, CSA - designed as B and Medard - designed as C), from the North Bohemian Coal Basin were used in the experiments.

These samples represent partly detritic compact homogeneous coal with macroscopically visible inclusions of FeS_2 and other mineral impurities, and partly xylodetritic hard compact coal, partially intergrown with fine diagenetic FeS_2 inclusions.

The samples were milled to under 1 mm and classified by sieving into required fractions. Basic parameters of the coal, as obtained by chemical analysis, that are important from the point of view of evaluation of magnetic separation efficiency, namely the grade of ash A^d , total sulphur S_t^d , combustible matter C^d and water W^a are shown in Table I.

TABLE I Characteristics of coal samples

Sample	W^a	A^d	C^d	S_t^d
A	6.74	24.20	75.80	2.15
B	8.52	8.66	91.34	2.74
C	15.10	6.40	93.60	2.18

RESULTS AND DISCUSSION

To demonstrate and to compare the efficiency of both HGMS and OGMS techniques, the size fraction 0.1 - 0.3 mm of the feed was selected. Results of magnetic separation obtained under partially optimized conditions (that enabled us to obtain the recovery of the combustible matter into the non-magnetic product higher than 90 per cent) are presented in Tables 2, 3 and 4.

It follows from the results that:

1. The recovery C^d of combustible matter into the non-magnetic fraction is higher than 90 per cent for all three samples, using both techniques.

2. The recovery of ash A^d into the magnetic fraction in the case of the HGMS technique is higher for all three investigated samples as compared to the OGMS technique.
3. The recovery S_t^d of total sulphur into the magnetic fraction in the case of the HGMS technique is higher for all three samples as compared to the OGMS technique.

TABLE 2 Magnetic separation of sample A

PRODUCT	YIELD %	GRADE %		RECOVERY %			METHOD
		A^d	S_t^d	A^d	S_t^d	C^d	
Mag	6.43	40.05	11.43	10.30	32.16	5.15	OGMS
Non-mag	93.57	23.93	1.65	89.70	67.84	94.85	
Feed	100.00	24.96	2.25	100.00	100.00	100.00	
Mag	16.72	57.92	10.48	33.65	72.70	9.90	HGMS
Non-mag	83.22	23.02	0.91	66.35	27.30	90.10	
Feed	100.00	28.88	2.42	100.00	100.00	100.00	

TABLE 3 Magnetic separation of sample B

PRODUCT	YIELD %	GRADE %		RECOVERY %			METHOD
		A^d	S_t^d	A^d	S_t^d	C^d	
Mag	10.72	15.37	8.81	22.19	32.98	9.80	OGMS
Non-mag	89.29	6.44	2.15	77.81	67.02	90.20	
Feed	100.00	7.39	2.85	100.00	100.00	100.00	
Mag	7.94	25.68	15.23	30.09	46.01	6.33	HGMS
Non-mag	92.06	5.15	1.54	69.91	53.99	93.67	
Feed	100.00	6.78	2.63	100.00	100.00	100.00	

Magnetic separation of non-classified (i.e. non-dedusted) samples did not yield satisfactory results, either by HGMS nor by OGMS techniques. In the case of OGMS it is necessary to classify the pulverized coal so that the minimum particle size is 40 μm . In the case of HGMS it is possible to reduce the minimum particle size to about 20 μm . These limiting values are approximate and must be

determined experimentally in view of their dependence on mechanical properties of coal.

It follows from the results of classification of the coal samples on a vibrating screen that the concentration of ash and sulphur reaches the maximum in the finest fractions [8, 9, 10]. As an example, chemical assays of fractions of coal samples that were taken directly from the milling circuits of two thermal power plants are presented. The results are shown in Tables 5 and 6.

TABLE 4 Magnetic separation of sample C

PRODUCT	YIELD %	GRADE %		RECOVERY %			METHOD
		A ^d	S _t ^d	A ^d	S _t ^d	C ^d	
Mag	10.65	11.25	3.89	17.00	21.60	9.69	OGMS
Non-mag	89.34	6.56	1.66	83.00	78.31	90.31	
Feed	100.00	7.06	1.89	100.00	100.00	100.00	
Mag	5.82	25.16	13.70	22.70	41.77	4.66	HGMS
Non-mag	94.18	5.28	1.18	77.30	58.23	95.34	
Feed	100.00	6.43	1.91	100.00	100.00	100.00	

TABLE 5 Characteristics of different size fractions of coal from Nastup-Tusimice open-cast mine, Prunerov II thermal power plant.

FRACTION mm	YIELD %	GRADE %		RECOVERY %		
		A ^d	S _t ^d	A ^d	S _t ^d	C ^d
+0.04	70.10	34.17	1.47	66.54	49.69	72.10
-0.04 +0.02	20.80	37.46	2.59	21.66	25.90	20.32
-0.02	9.10	46.65	5.58	11.80	24.41	7.58
Feed	100.00	35.99	2.08	100.00	100.00	100.00

It can be seen that mere dedusting of the finest fraction (- 20 μm) makes possible to reduce the concentration of sulphur and ash-forming minerals, with simultaneously minimum loss of combustible matter.

As has been mentioned above, for the HGMS technique to be used, it is necessary to remove the - 20 μm fraction. The removal of - 40 μm fraction from the feed prior to the application of the OGMS technique is more disadvantageous. It follows from the example presented in Table 5 that about 34 per cent of ash and 50 per cent of total sulphur can be removed, but the loss of combustible matter exceeds 27 per cent, a somewhat higher percentage.

TABLE 6 Characteristics of different size fractions of coal from Melnik thermal power plant.

FRACTION mm	YIELD %	GRADE %		RECOVERY %		
		A ^d	S _t ^d	A ^d	S _t ^d	C ^d
+0.04	69.65	32.06	0.82	57.36	57.30	77.48
-0.04 +0.02	16.68	50.70	1.11	21.73	18.50	13.47
-0.02	13.67	59.55	1.77	20.91	24.20	9.05
Feed	100.00	38.93	1.00	100.00	100.00	100.00

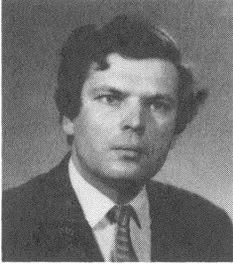
CONCLUSIONS

Results of magnetic separation of classified samples of coal presented above indicate that the high-gradient as well as open-gradient magnetic separation are potentially promising techniques that allow us to reduce, in a relatively simple manner, the concentration of undesirable impurities (pyritic sulphur up to 50 per cent and ash-forming minerals up to 40 per cent, with acceptable loss of combustible matter of 10 per cent) in dry pulverized coal.

It is imperative to remove the finest particle fractions prior to magnetic separation, for the process to be viable. Depending on the type of coal, the limiting minimum particle size that can be processed by OGMS is about 40 μm , while for HGMS the limit is as low as 20 μm . The removal of the finest particles improves the results of magnetic separation (the recovery sulphur and ash into the magnetic fraction increases), while the recovery of the combustible matter into the non-magnetic product decreases. It can be concluded from the results of the coal preparation prior to magnetic separation that the HGMS technique appears to be more effective than the OGMS method.

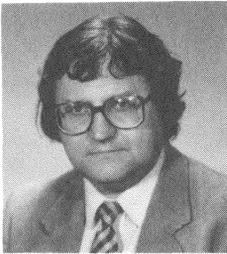
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