New Highly Efficient Dry Separation Technologies of Fine Materials

V.A. Arsentyev, A.M. Gerasimov, S.V. Dmitriev and A.O. Mezenin

Abstract During cleaning of high-ash coal mainly "wet" processes are used which require 5–10 tonnes water consumption per 1 tonne of coal. Arrangement of recycling water supply reduces demand in "fresh" water, but transportation of huge volumes of water slurry requires high-energy consumption. Dry cleaning of low-rank coal which has not been exposed to preliminary preparation is inefficient. It was suggested that to provide dry cleaning of high-ash coal it would be reasonable to expose it to chemical heat treatment first, and then to direct the treated coal mass for physical and mechanical cleaning to get the low-ash high-caloric product. It has been determined that in black coal exposed to medium temperature pyrolysis, as well as in brown coal, improvement of incombustible mineral fraction liberation is observed that facilitates further beneficiation with the use of a combination of high-intensity magnetic separation and triboelectrostatic separation. It has been determined that cleaned semicoke substantially exceeds both initial and cleaned coal by its qualities as a solid fuel, and tailings of semicoke dry cleaning can be utilised.

Keywords Low-rank coal · Dry cleaning · Dry processing · Semicoke Magnetic separation · Triboelectrostatic separation

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Introduction

Mined coal is exposed to long processing flowsheet ending with its use as a fuel in the energy industry, metallurgy or chemical industry. There are several stages in this processing flowsheet at which the largest economic waste occurs and the environment is subjected to damage. For example, during coal cleaning mainly "wet" processes are used which require 5–10 tonnes water consumption per 1 tonne of coal. Arrangement of recycling water supply reduces demand in "fresh" water, but transportation of huge volumes of water slurry requires high-energy consumption.

Long-distance transportation of commercial coal is associated with expenses occurring due to movement of a relatively low-caloric product containing in addition from 15 to 25% of ballasting ash fraction.

It is a real disaster for the companies of the energy industry to store large volumes of coal combustion waste including ash and slag.

Considering the above processing flowsheet of coal usage after mining, one may pinpoint the following technical issues, a solution of which would significantly increase its efficiency:

- the transition from wet to dry coal cleaning at the places of coal mining;
- producing high caloric low-ash fuel during cleaning, which is suitable for use both in energy industry and metallurgy;
- separation of ash fraction of coal during its deep cleaning in the form which allows using it as raw material for commercial product manufacturing.

The accumulated experience shows that dry cleaning of high-ash low-rank coal which has not been exposed to preliminary preparation is inefficient [1, 2].

At the same time, there is a current steady trend in world practice to enhance coal beneficiation improving its qualities and coal product range expansion [3–5].

Analysis of previously performed studies shows [6–8] that on the basis of the task set, i.e. processing of coal without water use, the following processes are of the greatest interest:

- the Green Fields Coal Co. (USA) process, including deep drying and fine grinding of coal followed by its gravity separation in air cyclones collectors;
- the Convert Coal, Inc. (USA) process, including coal pyrolisis and separation of pyrrhotite by means of magnetic separation;
- the SynCoal (USA) process of the Rosehud SynCoal Partnership (USA) company, including coal pyrolysis and separation of ash by means of pneumatic separation;
- the Thermocoke process of the Sibtermo (RF) company including partial gasification of brown coal with the subsequent separation of ash by pneumatic separation.

It is worth mentioning that the main purpose of the above technological approaches was the production of water-free high caloric fuel on the basis of low-ash coal, mainly brown.

At the same time, testing of all the above technologies proved that during heat treatment of coal which corresponds to the *mode* of coal pyrolysis, physical and chemical transformations of coal mass take place which substantially influences its further processing, i.e. the following:

- the decrease of mechanical strength of coal due to moisture and volatile matters removal;
- exposure of particles of non-combustible mineral fraction along the boundaries of contact with the carbon part due to differences in physical and chemical properties resulting from heat impact;
- the increase of the calorific value of residual coal due to moisture and volatile matters removal;
- change of physical and chemical properties of ash forming minerals due to heat impact.

On the basis of the above, one may suggest that to provide for dry cleaning of high-ash coal, it is reasonable to expose it first to heat treatment, and then direct the treated coal mass for physical and mechanical cleaning to get the low-ash high-caloric product (coal char fuel).

This approach is shown in Fig. 1.

Implementation of the above chemical transformations provides new process potential in further processing of heat-treated coal, i.e. the following:

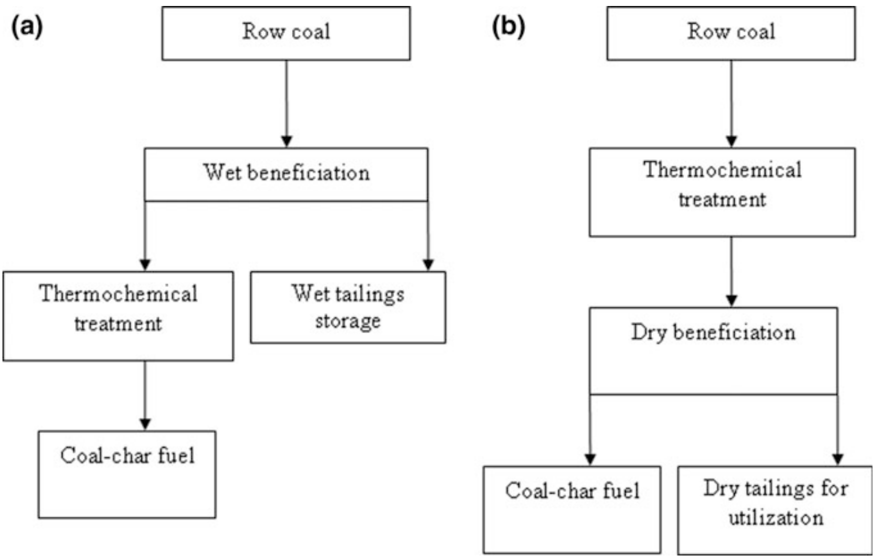

Fig. 1 High ash coal processing flowsheets: **a** Wet beneficiation; **b** Dry beneficiation

- the decrease of power consumption for crushing and grinding due to a decrease of mechanical strength;
- the possibility of deep removal of ash fraction from coal with the use of only dry cleaning processes;
- the possibility of agglomerated semicoke production;
- possibility to use burnt ash forming minerals fraction for the production of special binding agents, additives to concrete and construction materials.

Experimental

Analysis of the previous studies [6–8] shows that medium temperature pyrolysis at a temperature of 450–600 °C is the most reasonable method of heat modification of coal.

Within this temperature range, the following process problems are solved:

- coal mass porosity increases and mechanical strength decreases, which provide good exposure of ash fraction at subsequent grinding;
- sulphide minerals being part of non-combustible fraction acquire higher magnetic susceptibility;
- clay minerals being part of non-combustible fraction lose crystal moisture, enlarge and lose the capacity to water regain;
- the generated carbon material—semicoke—has high calorific value;
- the volume of generated volatile fractions is sufficient for the provision of autothermal flow of medium temperature pyrolysis process.

For the liberation of ash fractions in high-ash coal, it is usually required to grind material up to particle size less than 1 mm. To separate ash fractions with such particle size, it is possible to use pneumatic separation, magnetic separation and triboelectrostatic separation. The use of pneumatic separation for extraction of ash fraction out of coal has been studied rather well [9, 10] and has not been considered in this study. Studies on the use of magnetic and triboelectrostatic separation for extraction of ash fraction from coal proved their prospectivity [10–14]. The main difficulty for the processes of separation of mineral powders with the particle size less than 1 mm by their magnetic and electrical properties is provided by the availability of internal friction forces in powders which hinder effective separation of mineral particles. Studies proved that to overcome the internal friction forces in mineral powders, one may use the effect of vibrofuidization occurring during overlapping of certain vibrations [15]. The use of this effect allowed the creation of effective separators for separation of fine mineral powders by magnetic and electrical properties described in [16] and used in this study.

The studies have been conducted on samples of hard coal having the humidity of 1.8%, ash content of 14.8%, devolatilisation of 34.7%.

Experiments on the determination of the optimal temperature of coal pyrolysis have been performed in the standard vessel as per Fisher. On the basis of data given

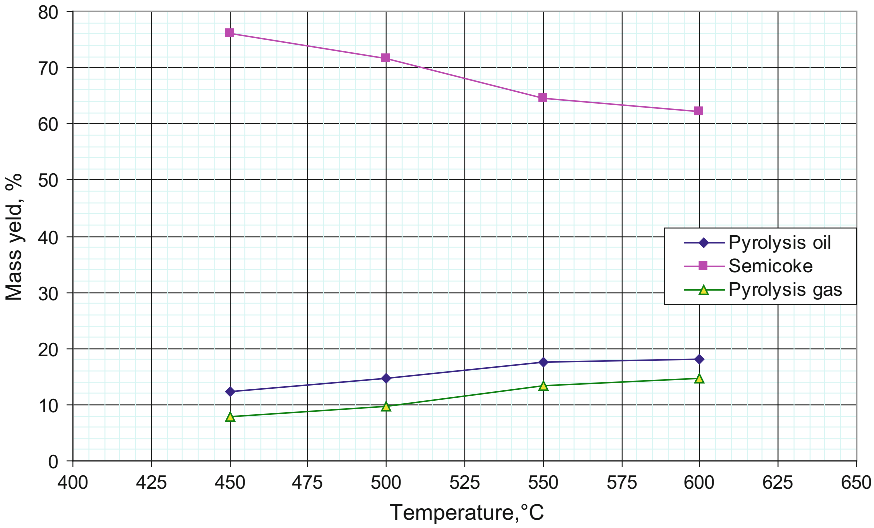

Fig. 2 The coal pyrolysis by Fisher method results

in Fig. 2, $t°$ = 550 °C has been accepted as the optimal temperature of coal pyrolysis.

Semicoke sample for conducting process studies has been made at a laboratory pyrolysis unit having a 4 litres chamber, externally heated.

Pyroysis of the coal sample under test at a laboratory unit showed that at $t°$ = 550 °C, semicoke yield makes 63.8%, the yield of pyrolysis oil is 11.4%, pyrolysis gas—20%, pyrogenetic water—4.7%, that is in good correspondence with the results received by Fisher's method.

Coal with particle size 10–20 mm has been treated. Samples of raw coal and semicoke were grinded in laboratory hammer grinder up to 0–2 mm particle size. The results of classification of grinded products by particle size and distribution of ash fraction by particle sizes are given in Fig. 3. The data in Fig. 3 shows that thermo chemical treatment of coal contributed to the substantial improvement of ash fractions liberation—recovery of ash fractions with grinding of semicoke to particle size 0–0.5 mm makes more than 90% if compared to 70% for raw coal.

Magnetic separation of raw coal and semicoke grinded up to particle size 0–0.5 mm was conducted in a laboratory magnetic separator in two steps—the first was at magnetic field induction of 0.35 T, the second—at 1.7 T.

Results of magnetic separation are given in Table 1 and show that during separation of coal exposed to heat treatment, recovery of ash fraction into low-intensity magnetic product increases almost threefold and recovery into high-intensity magnetic product increases twofold.

Triboelectrostatic separation of the non-magnetic product allows removal of about 30% ash fraction, that allows getting semicoke of the satisfactory quality (Tables 1 and 2).

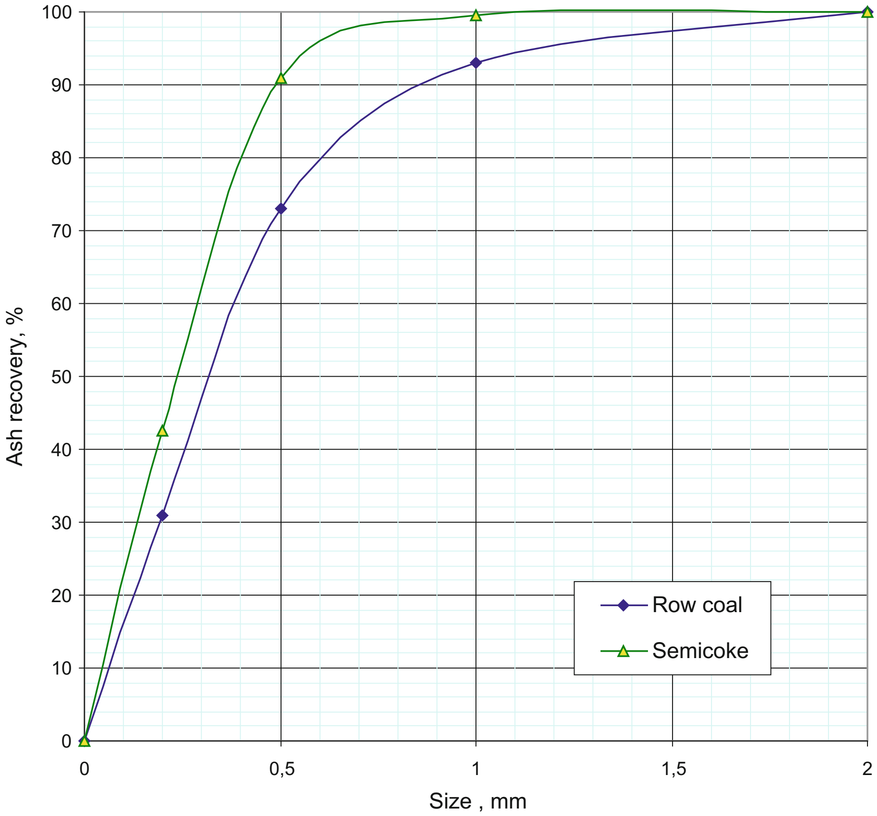

Fig. 3 Size and ash analysis of row coal and semicoke grinded to 0–2 mm size

Table 1 Results of raw coal and semicoke cleaning

Products	Raw coal			Semicoke		
	Mass yield (%)	Ash content (%)	Ash recovery (%)	Mass yield (%)	Ash content (%)	Ash recovery (%)
Low intensity	0.6	55.0	2.1	2.1	60.2	6.0
High intensity	3.1	67.2	13.3	9.2	63.4	27.8
Conductor	9.7	52.2	32.3	10.1	58.7	28.3
Non-conductor (concentrate)	86.6	9.4	52.1	78.6	10.1	37.9
Feed	100.0	15.6	100.0	150.0	21.0	100.0

Table 2 Comparative characteristic of studied products by ash specific yield

Parameters	Raw coal		Semicoke	
	Without cleaning	With cleaning	Without cleaning	With cleaning
Calorific capacity (MJ/kg)	12.55	15.06	23.72	25.94
Ash content (kg/kg)	0.158	0.100	0.195	0.100
Ash specific yield (kg/MJ·10^3)	12.6	6.6	8.2	3.9

Results Discussion

The results received to prove the practicability of using thermochemical modification of high-ash black coal to increase the efficiency of its dry cleaning with the use of physical and mechanical processes.

It has been determined that in black coal exposed to medium temperature pyrolysis, as well as in brown coal [8], improvement of incombustible mineral fraction liberation is observed that facilitates further beneficiation.

It has been proved that high-intensity magnetic separation and triboelectrostatic separation are effective methods of cleaning fine-grained high-ash coal. It has been determined that the efficiency of using these methods for non-combustible mineral fractionation increases after thermo chemical heat modification of high-ash hard coal. Combining high-intensity magnetic separation with triboelectrostatic separation increases the efficiency of high-ash coal and semicoke cleaning. To evaluate the efficiency of thermo chemical modification of coal and of cleaning both coal and products of its modification, it is reasonable to introduce such a parameter as ash specific yield per calorific capacity unit:

$$A_{\mathrm{w}} = \frac{A_{\mathrm{c}}}{W} \cdot 10^3, \tag{1}$$

where

A_{w} ash specific yield per calorific capacity unit, kg/MJ;
A_{c} ash content in product, kg/kg;
W product calorific capacity, MJ/kg.

Use of this parameter (Table 2) shows:

- combined dry cleaning of coal allows to decrease ash specific yield 1.5–1.7 fold;
- semicoke from high-ash coal without cleaning insignificantly exceeds initial coal by ash specific yield, i.e. 3.44 against 4.39;
- cleaned semicoke 2.5 times exceeds initial coal by ash specific yield.

Final tailing of semicoke dry cleaning containing more than 50% of combustible mineral fractions is raw material for the production of a binding agent for construction, i.e. cement analogue, which can be derived by means of their combustion without additional fuel and used for back filling of coal mines.

Conclusions

Cleaning high-ash coal without using water requires a new approach to the organisation of its conversion. To create conditions providing the possibility of dry cleaning of high-ash coal requiring its fine grinding for exposure non-combustible mineral fractions, it is reasonable to perform thermochemical modification of coal before cleaning. Medium temperature pyrolysis at $t° = 450–600$ °C is an effective method of modification of high-ash coal providing possibility of dry cleaning derived semicoke with the use of high-intensity magnetic separation and tribo-electrostatic separation.

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