Polish experiences in fine coal processing

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Abstract. The amount of fine-grain waste containing grains of coal, coke, coke breeze, etc. is
significant and it is not being visibly reduced. Particularly significant are quantities of coal
slurries generated from the current operations of hard coal mines and settlers previously handed
over to local authorities as reclaimed land. The available reported quantities of coal slurries vary
widely and range from 0.5 (current production) to over 20 million tonnes (mainly collected in
operational and reclaimed settlers).

The group of fine-grain fuel sources include, inter alia, coal slurries, including sediments,
flotation tailings from coal beneficiation, brown coal waste dust, coke breeze from the processes
of gasification of residues from crude oil processing and fluidized bed gasification of solid fuels,
coke breeze from decarburization of fly ash, coke dust, waste from production and processing of
carbon and graphite products. The use of these fine-grain materials and waste often encounters
serious difficulties, inter alia due to the high water content, heterogeneity, fragmentation, low
and variable energy characteristics. With the aim to rationalizing their use in recent years
technologies have been extensively developed and implemented for recovery of fine-grain
materials and waste to produce commercial fuels.

1. Systematics of coal mining waste

Wastes from hard coal mining, also called coal tailings, are among the so-called mineral waste
materials generated in the processes of extraction, beneficiation and processing of minerals.
Traditionally, mineral waste materials are divided into four groups, taking into account the technical
characteristics of these wastes and the operating processes and technology, from which they are
generated [1, 2]:
- accompanying minerals - potential mineral resources found in the main mineral deposit, which
generally can be selectively extracted;
- mining waste, also known as extraction waste - rocks from the mining and preparation works opening up the main mineral deposit in underground and open pit mines;
- tailings - rock material extracted along with the mineral and separated in the main mineral beneficiation processes;
- secondary processing waste - remnants of the main mineral processing, generated in the production processes of commercial products (e.g. energy waste).

The mineral composition of these waste materials broken down into the dominant petrographic groups is given in table 1.

| Rock   | Description                                                                 | Comments                                      |
|--------|------------------------------------------------------------------------------|-----------------------------------------------|
| Slate  | sedimentary, detrital rock of black colour, less frequently dark grey colour,  | different thickness of layers,               |
|        | with a layered (slated) siltstone and pelite texture                         | relatively low mechanical strength, slate     |
|        |                                                                              | separateness                                  |
| Mudstone | sedimentary, detrital rock of dark grey to black colour, solid,              | rocks of varying mechanical strength,         |
|        | with non-directional, compact, massive, siltstone texture, occasionally the  | depending on the content of coal              |
|        | rock contains siderite nodules (spherosiderite – sedimentary carbonate rock,  |                                               |
|        | of grey-brown to brownish-yellow colour with high-density, compact, massive,  |                                               |
|        | non-directional texture                                                      |                                               |
| Sandstone | sedimentary, detrital rock of light to dark grey, solid, with non-directional| rock with a fairly high mechanical strength,   |
|        | texture, less frequently slightly layered, compact, massive, psammitic        | depending largely on sandstone binder         |
|        | sometimes mixed with psammitic fractions                                      | (the more clayey, the less resistance)        |

Waste from the coal mining industry is generally divided into three groups: mining wastes, tailings and secondary processing wastes, taking into account their technical characteristics, the operational and technological processes.

Mining wastes, also known as extraction wastes, are rocks from the mining and preparation works opening up the main mineral deposit, mainly cap and interlayer rocks. They represent an average of about 20% of the total mass of waste [4].

Tailings include rock material extracted along with the mineral and separated in the mineral beneficiation processes (e.g. sorting, crushing, washing, flotation), and their share in the total mass of waste is on average 78%.

The third group includes secondary processing wastes, i.e. the remnants of the main mineral processing, generated in the production processes of commercial products.

The coal beneficiation process in mechanical preparation plants of hard coal mines generates coal slurries. These are the finest-grain grades of grain size below 1 mm, where grades below 0.035 mm make up to 60% share in the slurry composition. Depending on the quality parameters (ash and sulphur content, calorific value), such slurries can be transferred as an ingredient to energy mixtures or are dumped in earth settlers of individual mines [5, 6]. Most of slurries have been collected in settlers, as there were no customers interested in buying them. Dumped slurries were treated as waste of coal preparation processes. Most of this waste was actually energy fuel. For this reason, in recent years, the interest in combustion options has increased.

Coal tailings are also used in the manufacture of building’s construction products - as an essential raw material for obtaining slate aggregate, i.e. a lightweight building construction aggregate used in the manufacture of lightweight concrete, as well as an essential raw material or component for the production of various building construction elements, such as bricks or roofing tiles [7].
Currently about 0.5% of generated waste is utilized in this way. The waste is also added to the charge in the production of cement, in order to adjust the main module of cement clinkers. Coal tailings may also be useful for the production of refractory materials, but only if they have a high content of \( \text{Al}_2\text{O}_3 \). Part of coal tailings is transferred to preparation plants for recovery of coal contained in the waste. Currently about 9% of generated waste is utilized in this way. The residue after the recovery of coal (secondary waste) is re-dumped or used in hydraulic backfilling or building materials industry. Attempts have been made to recover metal concentrates from coal tailings, including aluminium, iron, titanium, germanium and gallium. Fine coal waste can also, after mixing with a compound fertilizer and peat, be used for biological reclamation and restoration of the fertility of devastated land, or reclamation of soil.

Flotation wastes due to a significant thixotropy, high humidity and difficulties in transport have not yet found an industrial application [8, 9]. These wastes can be used as a material for filling abandoned workings in mines or to seal the surface stockpiles, while post-flotation wastes from beneficiation of coking coals with calorific value more than 5000 kJ/kg (coal slurries) can be used as fuel for the production of building construction ceramics, and after beneficiation as an additive to energy fuel.

**Some directions of use of recyclable coal-accompanying materials**

The qualitative research conducted in various research centres shows that these materials have the quality features appropriate for many applications [10, 11]:
- Hydro construction and engineering,
- Manufacture of construction products and refractories,
- In agriculture as fertilizer or substrate,
- For recovery of coal, as well as low-energy material (slurries) for combustion in power plants,
- As a filling and sealing material in engineering works.

Coal wastes may be used in hydro construction for building river dams and embankments of settlers and to strengthen the shipping channels, as well as in the road construction industry for building road and railway embankments. Applications in marine building construction include the construction of embankments, coastal protection and of wharves.

**2. Directions to optimize the management of fine-grain materials and coal tailings**

The most common model for the management of coal slurries is their supply to coal-fired power plants and, to a lesser extent, to industrial energy generation plants. Such a solution, though very simple and practical, is not optimal for environmental as well as economic reasons. In this way, approximately 30% of water is transported, often with a heavy contamination of transport routes and user sites. In the case of fluidized bed combustion, water-slurry pulp is used, having a water content well above 30%.

Undertaken studies, research and trials for optimizing the management of fine-grain materials and waste for fuel production include [12]:

1) qualitative assessment of fine-grain materials as a source of heat energy,
2) technologies for beneficiation of fine-grain materials for the purposes of energy processes.

While the qualitative assessment processes enable identification of the possibilities and conditions for direct management, beneficiation technologies indicate the possibilities and conditions for their use to generate high-quality stand-alone fuels or components for their production.

Technological processes generally provide conditions to influence the quality of fine-grain materials. An example might be the generation of coal slurries from water suspensions; for instance only by replacing the belt presses with chamber filter presses a higher drainage of slurry is achieved together with an improved energy performance of slurries – figure 1. Poor quality of coal slurries is also due to the lack of selective separation of water and slurry suspensions in mines, and also often unoptimized operation and emptying of slurry settlers.
The caking processes of fine-grain materials and coal tailings for energy purposes. In recent years, a considerable progress has been achieved in the caking of coal slurries, coke dust, coal and biomass blends and alternative fuels in the processes of briquetting.

Regardless of the direction and method of processing, in some cases significant problems are caused by the loosened structure of coal slurries, which determines the performance of coal blending and biomass blends, achieved durability of granulated materials and effectiveness of slurry drying processes. This problem has not been fully resolved and it requires further testing and trials.

The process for caking fine-grain materials and coal tailings should be selected mainly based on market requirements [13].

The most durable and geometrically adjustable caking of fine-grain materials is guaranteed by the **briquetting process**. It is important to properly prepare the feed and adjust the type and amount of binder added. As a result of blending coal slurries, sediment and flotation concentrate and addition of a specific binder, production process has been established for coal briquettes of calorific value of 16 to 24 MJ/kg. The size of briquettes is adjusted to the requirements of customers.

A similar work has been performed for the briquetting of brown coal, biomass, selected municipal waste with and without binders. The quality of briquettes obtained was affected most by the pressures applied, this also should explain the highest mechanical strength of briquettes obtained from briquetting stamp presses. Particularly interesting results were obtained by pressing chopped straw; as a result of friction and release of heat from the feed, water evaporates and the concentrated feed is subject to a strong curing with released resin substances.
Granulation process was applied to graphite dust caking [14]. Due to the hydrophobicity of graphite grains it was necessary to choose the appropriate binder. Granules with the highest mechanical strengths were obtained as a result of additional thermal treatment. Depending on the binder used, hardening of granules can occur within 180-240°C and at higher temperatures. Granulation of coal slurries and their blends with coal and/or sawdust is a simple process; however, the granulation installations are characterized by relatively low yields. In recent years there has been a huge interest in caking coal slurries; the simplest solution appeared to be the agglomeration process. In cases where a high mechanical strength of grain agglomerates or their specific shape is not required, it is sufficient to intensely mix the feed to cause creation, merging and cross-sticking of grains to form an agglomerate. Mechanical stability of the agglomerate can be raised through the proper preparation of the feed and the addition of selected binders and additional granulation. The effect of different binders on the grain size of agglomerates, after ageing, is illustrated by the results in table 1. With strongly damp clayey coal slurries there is no full relaxation of their structure and proper mixing with a binder, due to which the resulting agglomerate is characterized by larger grains and lower compressive strength.

Agglomerate subjected to ageing by weathering, in most cases is subject to further curing. The year-round experience from heaping agglomerate in the stock yard showed that under the influence of rain and snow and the impact of the sun and changing temperatures the surface of the agglomerate heap developed a shell (2 to 8 cm thick) that insulated the agglomerate (figure 3).

Figure 3. Dumping ground surface after one year of agglomerate storage (source: [8])

3. Dewatering and drying of fine-grain materials and coal tailings

Energy properties of fine-grain materials and coal tailings depend to a large extent on their moisture; for these reasons, it is sought to minimize the water content in the fuels or fuel additives produced from them [15]. As previously mentioned, the processes most frequently used for this purpose are the processes of filtration, gravity and evaporation under normal weather conditions. In these cases, depending on the type of material, moisture content can vary in a wide range from 20 to 60%.

While until recently coal slurry drying seemed to be not economically viable, now taking into account the access to sources of waste heat this issue should be seriously considered and worked around. The technical progress made in the design of driers of flotation concentrates and coals points to the possibility of rapid deployment of drying processes for coal slurries and their mixtures with additions of biomass. In a number of cases there is an interest and need to use installations for a periodic drying of biomass.

The viability of using combustion engines fired with coal bed methane used in mines was pointed out even earlier. Exhaust gases from the combustion of methane are characterized by a relatively high temperature of 400°C. Mines implementing the program for coal bed methane management are increasingly turning to gas engines as a source of electricity. So far, the exhaust heat has not been utilized. Also system power plants increasingly often consider additional sources of electricity based on internal combustion engines fuelled by natural gas. In all these cases, the exhaust heat can be used for the drying of fine-grain materials and coal tailings.
The traditional source of heat in the drying of flotation concentrates, slurries and their concentrates are exhaust gases from the combustion of coal dust, coke oven gas and coal bed methane. Drying of coal slurries, so far, is not very common. In Germany, for example, there was used a tumble dryer with a fluidized bed combustion for drying coal concentrate obtained from flotation beneficiation of coal slurry and flotation tailings; obtained pulverized coal with a moisture content below 3% was supplied as fuel for cement plants and as a reducing agent for blast furnaces. For the selection of the type of drying kiln, taking into account sources of heat and the possibilities to dry coal slurries, flotation tailings and biomass and their mixtures, tumble dryers, air (tubular) and fluidized bed kilns are taken into consideration, inter alia. Selection of a solution depends on the local conditions and preferences of the entity concerned.

A number of fine-grain materials and coal tailings encounter considerable difficulties in their rational use as fuels or sources of heat, due to their high fragmentation, heterogeneity and water content. The solution to these problems is offered by the processes of caking and drying of fine-grain materials and coal tailings.

The research and testing carried out have led to the development of technology for caking coke and coal dust, graphite, biomass etc. Briquetting processes have been implemented, inter alia, for the production of coal fuel briquettes and eco-pea coal. For the purpose of smelting and foundry, granulated graphite is produced. Based on the assumptions developed in technological and technical terms, an installation for coal slurry agglomeration is being made, with a capacity of 80 tonnes/h.

The properties of coal slurry agglomerate are significantly influenced by addition of binders. Out of the various binders tested the best results are guaranteed by the addition of quicklime, which on the one hand binds the water contained in the product and on the other hand, by reaction with carbon dioxide, preserves the structure of the agglomerate. The conducted economic analyses show that the payback period may be achieved within a period of several months to two years.

Previous works on optimizing the management of fine-grain materials and coal tailings will be extended to include viability of their drying. This, in particular, using sources of waste heat, such as from internal combustion engines or a dried material.

The designed and developed technologies to optimize the management of fine-grain materials and coal tailings are intended for use not only by mining companies and coal fuel distributors but also by power plants, power and heating plants and heating plants.

4. Waste storage

The materials deposited on the heaps originated during coal mining and are much varied. The basic types of materials have markedly different physical-mechanical properties and petrographic or chemical composition [16]. In the heap bodies there are rocks with included coal, low grade coal substance, coal dust from cleaning cross cuts, washery refuse, slag and often also rubble and municipal waste. Especially old heaps contain high percentages of organic mass. Organic mass is found there along with greyish, crumbling coal claystones and siltites. Clay minerals and clastic quartz prevail in the groundmass and there is eugster in places. Accessory pyrite is common, which weathers quite rapidly into limonite and sulphates that are fast washed away with rain usually. The waste rock is not mechanically sorted and it contains boulders to clayey-silty particles. Dominant are stone fractions with fragments of different sizes, from first centimetres to decimetres. Erosion factors cause further fragmentation (disintegration of sandstone into sand, laminated disintegration of aleuropelites along the cleavage plane).

The calorific effect of coal substance alteration leads to a considerable heating of the surrounding sedimentary rocks and their gradual natural firing. Clay sediments, during heating of which the temperature of 600 °C was not exceeded, are not much different in their mineral composition from grey sediments before alteration. The most prominent changes occur in the association of clay minerals, kaolinite and illite. Red colouring of the thermally altered sediments is characteristic and is caused by finely dispersed hematite. Clay-silty rocks exposed to higher temperatures (900 - 1200 °C) show more distinct variations in the mineral composition and their alteration is connected with the
formation of porcelanite and vitreous phase. The overall character and colour of porcelanite vary. The fired porcelanites in the reducing manner are black or grey; the oxidically fired porcelanites are red. The structure of such rocks may be significantly porous. At running out of reddish-brown vitreous mass on the base of fired porcelanites, irregular cohesive and solid laminar bodies, which are placed on relatively loose material, form in the burnt-out waste rock (the so-called porcelanite sinters).

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