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The utilization of energy waste in Polish underground coalmines*

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The world mining as well as the Polish mining industry has used wastes to support the ceiling since the half of the 19th century. Waste rock was used for this purpose, which was rarely brought to the surface. It was applied in backfilling technologies, namely dry, hydraulic and pneumatic backfills. Particularly the hydraulic backfill, which underwent rapid development in the 1960s and 1970s, took advantage of large amounts of mining waste. The waste was an additive to backfilling sand, because it itself did not meet the standard requirements. "Fat" fraction waste were used, i.e. pebble, gravel and sand ones. The finest fraction (<0.1 mm) was inadequate, as it did not meet the standard requirements [4], even being used as a little additive caused pollution to surface and underground sediment traps. For that reason energy wastes, particularly fly ashes, were not used, millions of tons of which were directed to the surface sites. Attempts of using them for hydraulic backfills failed every time. Granulates made of fly ashes were appeared too expensive.
The turning point happened as late as the beginning of the 1980s. These were the times when so called suspension technology, mixing fly ashes with water in new proportions, was introduced in hardcoal mines. The hydraulic backfill required the use of a few mass parts of water and one part of backfilling material. Similar and sometimes even larger amounts of water were used in power plants while hydraulic transporting of fly ash to the tailing ponds. The suspension technology reversed the proportions. From 0.5 to 3.0 parts of fly ash are added to one part of water, 1.5 to 2.0 parts on average.
This technology was developed by a group of AGH scientific workers and power engineers [6]. First successful attempts took place in 1983; consequently the technology was introduced in KWK "Paryz" ("Paryz" hardcoal mine = KWK "General Zawadzki" then) [1]. The suspension was transported by a specially built pipeline linking the mine and the "Lagisza" power plant. A part of gallery was liquidated, after a month dams were dismantled and this allowed for research. Basic properties of suspensions were confirmed and, what is the most important, numerous opponents in those days could indirectly acquaint themselves with the technology.

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After introducing the technology in KWK “Paryz”, research and development along with implementation works were conducted in the following fields:

- physical, mechanical and chemical properties of suspensions, their binding process and properties after binding and hardening of suspensions consisting of different energetic waste as well as influence of other fine grained wastes or binding materials on their properties;
- designing and building installations for the production of suspensions;
- mining technologies using waste and water suspensions;
- legal questions on the use of waste in underground mines.

Properties of suspensions

Properties of suspensions result from the properties of wastes and water used and their combination. Waste tests are based on recognition of their elementary physical properties such as their specific weight, grain size composition and moisture content. Chemical composition of waste and chemical waste leaching are marked, particularly in case of chlorides, sulfates and heavy metals. As for extraneous waste, for example, energetic waste, the concentration of natural radioactive elements is also marked in order to assess possible danger from radioactive radiation.

These basic tests allow assessment of waste usability as a suspension component, particularly in case of possible danger to the environment.

Suspension tests are carried out just after its preparation, during binding and after an established seasoning period in set and modeled conditions.

Each time the following properties of suspension are marked before its hardening:

- density;
- fluidity – its tested on glass which allows initial and approximate assessment of possibilities of gravitational transport;
- viscosity and flow behaviour – rheological parameters allowing for more precise calculation of transport parameters;
- the amount of supernatant water – the maximum water volume gathered on the suspension surface is measured. The result is given in % as a ratio of water volume to the original suspension volume. The amount of supernatant allows forecast the amount of water to drain from suspension;
- binding (setting) time – the test is carried out by means of the Vicat apparatus and allows forecast the suspension behaviour after its delivery to the underground mine.

The suspension during the period of binding and hardening is seasoned in air-dry conditions or in heightened humidity and temperature (free standing air conditioner) during the period of at least 28 days, and usually it is longer. Hardened samples are subjected to the following tests:

- compression strength;
- collapsing behaviour – while soaking samples in water macroscopic evaluation of suspension resistance to water is carried out. The evaluation is made also after testing compression strength of samples soaked in water for 48 hours and then comparing its results with those from dry samples tests;

- compressibility – it is carried out in a similar way to testing hydraulic backfill materials. Its results allow assess future cooperation between the suspension and fault;
- filtration – it is carried out by means of different methods, generally it boils down to measuring the amount of water flowing through a sample of hardened suspension. The results allow assessment of suspension isolation capabilities.

The above tests are conducted according to standard PN/G-11011 [5]. Apart from these, there are also conducted other tests, which are not required by the standard, for example determining gas permeability – carried out by means of an original method developed for rock testing [8]. Model tests are conducted as for suspension usability for different mining technologies. The flow capability through a differently slopped rock fall zone (gob area) of suspension is tested through observations. A possibility of consolidating rock fall zone by means of suspensions is tested with the use of mechanical methods.

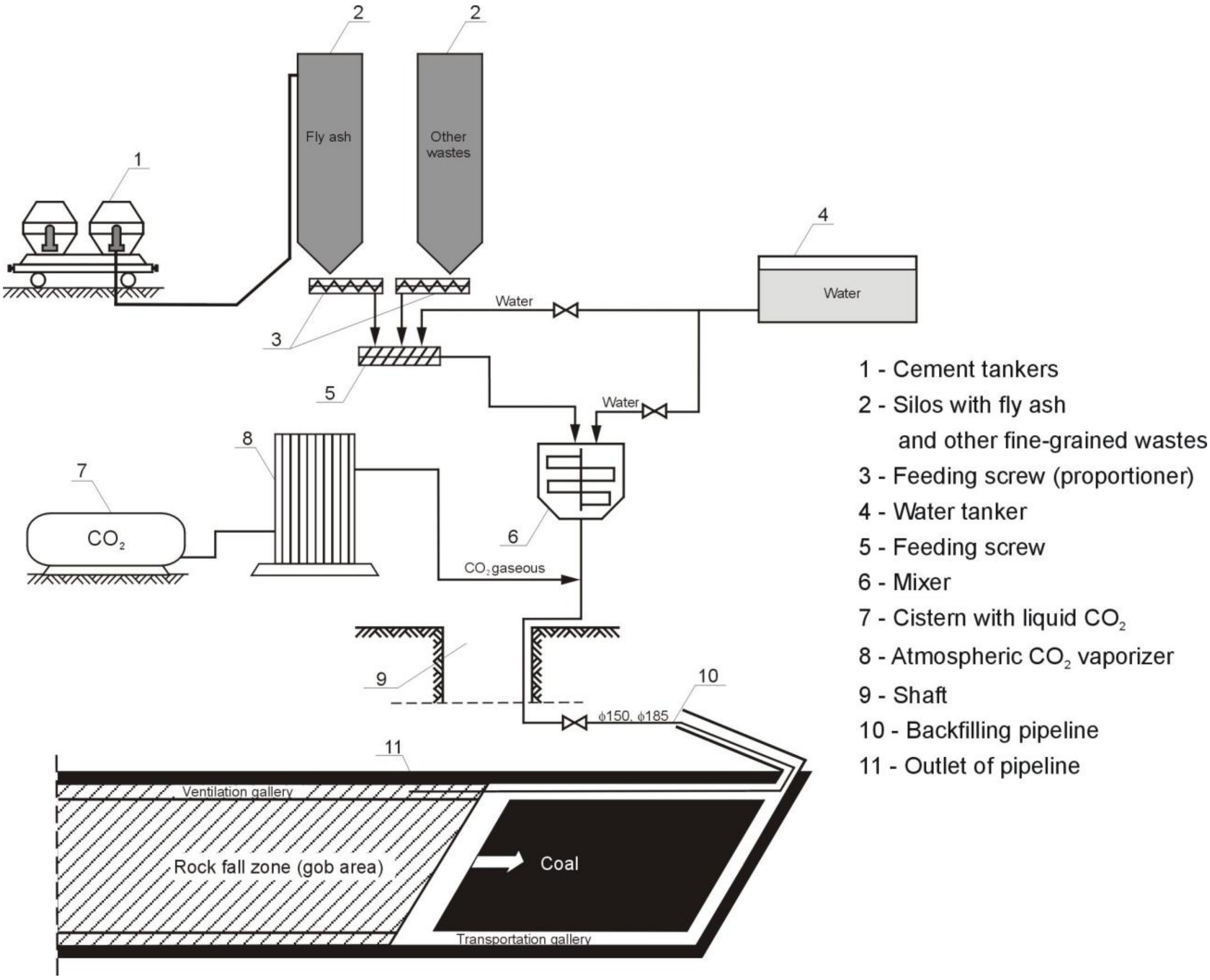
The laboratory research conducted for over twenty years allowed recognition of properties of suspensions prepared from different wastes. Fly ashes were tested along with flue gas desulfurization waste received by dry and semi-dry method. Fly ashes came from different Polish and foreign power plants; different kinds of coal were combusted in various furnaces, so their physical, mechanical and chemical properties were different. Therefore essential differences are observed as far as suspensions produced are concerned. An additive of different wastes, i.e. post-flotation waste, considerably changes the properties of a suspension, so does improving its strength by adding cement. What is more, water used in the production of suspension affects the properties to a lower extend depending on the level of its mineralization and so does the method a suspension is produced (a possibility of maintaining formula and mixing dynamics). Taking all the above into consideration the results cannot be averaged and suspension properties cannot be described unanimously. Therefore below there are given properties of suspensions without any additives, within the limits recorded during the tests so far:

- density:1.15 ÷ 1.88 Mg/m^3
- mass consistency (water to solid ratio) 1.0 ÷ 0.25. The bottom limit (1.0) separates the suspension from the sedimentary mixture, whereas the top limit (0.25) separates it from „pastes" that cannot be transported gravitationally;
- the maximum amount of supernatant water usually appears after 3 to 9 hours from the preparation stage comes to: 0.6 ÷ 12.5 %;
- the beginning of binding: 1.5 ÷295 hrs;
- the end of binding: 3.0 ÷ 480 hrs;
- compression strength after 28 days : 0 ÷ 4.6 MPa;
- compressibility after 28 days at the tension of 15 MPa : 9.4 ÷ 17.3 %;
- collapsing behaviour after 0.5, 4 and 48 hrs: all possible ways of behaviour;
- filtration: $10^{-4} \div 10^{-8}$ m/s;
- viscosity: 0.006 ÷1.25 Pa·s.

Installations for preparing suspensions

Suspension preparation requires an installation which can provide adequate mixing dynamics of components and their weight dosing in accordance with the established formula. The first installation built in the “Lagisza” power plant met the requirements, but it had low efficiency due to the cycling work of mixers. The installation in the “Lagisza” power plant and its linking with the KWK “Paryz” was the first and only solution. Next mixers were built in mines only. During the 1980s the suspension technology was introduced in hardcoal mines and different types of installations were built. Modern installations in Poland are built by the UTEX Company which specializes in managing power plant wastes. An example of such an installation which works in a hardcoal mine is presented in picture 1. The installation includes:

- a system of pneumatic offloading fly ashes transported with cement tankers. The ashes are off loaded into silos, the system is hermetic and offloading does not cause dusting the station;
- tankers for mine wastes and a silo for the possible use of materials modifying suspension (i.e. cement);
- a pipeline transporting water to the mixer;
- a continuous mixer;
- a system of feeders, scales and counters allowing precise dosing of applied suspension components;
- a computer system monitoring the installation;
- a decompression and addition of CO_2 to the suspension installation;
- a compressed air installation for cleaning the pipelines.



Picture 1. Technology of fly ash suspension with CO_2 utilization in a Polish underground coal mine (longwall system)

Technologies using suspensions

During the first period suspensions were used for filling useless galleries and this actually was waste deposition. However, when suspension properties were recognized, and the method of their production with an increased share of fly ashes was developed, there a rapid development of technologies using the new material followed. Currently fly ash suspensions are used in Polish underground mines for:

- grouting of roof fall rock zones (gob area);
- decreasing rock fall porosity in active longwalls;
- limiting of fire and methane hazard;
- liquidating useless galleries;
- building backfill plugs;
- filling voids behind the gallery support construction;
- building backfill plugs;
- filling shallow bedded post-exploitation voids and Weber voids;
- binding highly mineralized waters;

- backfilling in a shortwall mining exploitation system;
- creating artificial roofs during layer exploitation;
- a means of transport for inert gases (nitrogen, carbon dioxide).

The basic way of using suspensions is grouting of roof fall rock zones (gob area in longwall system). Rock fall zones in Polish hardcoal mines are characterized by variable porosity depending on the type of rocks, geometric parameters of the wall, the value of tensions and the time of their influence on the rock fall zone. The rock fall porosity in these mines is a disadvantageous phenomenon because of the possibility of air flow through the zone. It affects ventilation and can lead to an endogenous fire. The porosity influences the rock fall zone compressibility causing its enlargement which brings negative results to the surface and/or superincumbent rocks. The negative results can be limited or sometimes eliminated by grouting roof fall rock zones by means of fly ash suspensions. They can be delivered to so call old rock fall zones influencing the ventilation conditions or applied in case of active longwalls and additionally they can decrease the compressibility of the rock fall zone or even lead to its reconsolidation. When delivering a suspension to old rock fall zones the pipeline should be placed in the highest possible point. This can be achieved by placing the pipeline through neighbouring zones or, if this way is not possible, through the holes drilled from the surface or upper gallery. When grouting rock fall zones of the active longwall, suspension can be delivered from the upper (ventilation) gallery and the gallery can be liquidated at the same time, or from the head of the longwall by means of pipes extended behind the hydraulic support. These pipes, partly perforated, at the length of 10 to 12m, are placed at the sill at the intervals of about 10m. Amounts of the applied suspension have to be carefully chosen so as to avoid spilling it to the working surface of the wall.

Fly ash suspensions are used above all for liquidating useless galleries. It an easy, tested way usually requiring building solid dams and backfill plugs in the lowest part of the liquidated gallery. If there is too much water in the gallery, there should be developed a way of removing its excess. The above applies as well to grouting watered rock fall zones, as water basins were often liquidated during the grouting process. Fly ash suspensions are also used as material filling voids behind the gallery support construction and at the same time filling cracks in the cracking zone.

Fly ash suspensions have proved to be an excellent material for liquidating shallow bedded post-exploitation voids and Weber voids which occur during exploitation on the border of the rock layers. Both cases require drilling holes leading to the voids. Suspension is produced in the immediate vicinity of the hole or delivered from the mine installation. The superiority of this method over the earlier used method of filling voids with dry ashes or sand has been confirmed many times. The suspension technology has been efficiently used for liquidating voids originated during the shortwall mining exploitation. The backfill used often met the requirements of the hardened backfill.

The newest research [2,7] has shown that suspension is a perfect means of transport for inert gases used during fire actions. Tests conducted in hardcoal mines demonstrated that part of CO_2 delivered to the underground mine firmly binds in the suspension which allows assume a possibility of storing carbon dioxide in the underground during various routine works connected with the use of fly ash suspension.

Summary

In 2007, with the contribution of the authors, there were conducted surveys on the number and ways of using waste in the form of water suspensions in underground mines. Their analysis leads to the following generalizations:

- the majority of Polish mines uses the suspension technology for ventilation purposes above all;
- the demand from the mines for energy wastes is stable; in the years 2002-2006 it amounted to about 2.5 mln Mg/year;
- this amount of energy wastes and other, mainly post-flotation waste (about 0.92 mln Mg/year), and highly mineralized water cause the use of about 5.7 mln Mg of suspensions - that is about 4.5 mln m^3;
- calculations demonstrated that in the mines which use waste, about 85kg of suspensions containing 35kg of dry energy waste is used underground to 1 Mg of mined coal.

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