Laboratory testing of coal sludge granulation

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Introduction

Mining wastes, referred to also as post-extraction wastes are chiefly made up of rock that is extracted during mining extraction and development jobs that enable access and availability of key mineral deposits when overburden and interleaving rocks are to be removed. These wastes substantially contribute to overall amount of wastes and measured w/w they pose about 27% of all industrial wastes (Fig. 1).

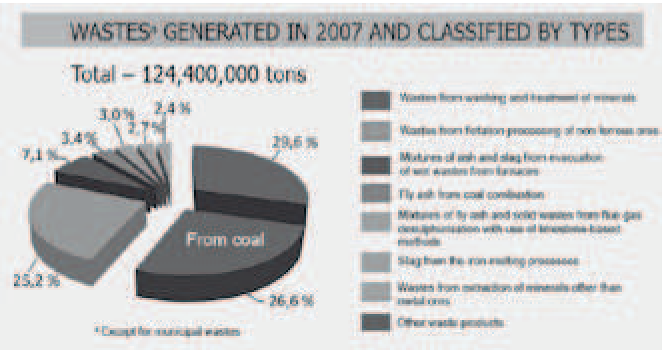

Fig. 1. Waste products (except for municipal wastes) generated in 2007 and classified by types [1]

The available reports published by environmentalists demonstrate that amount of such wastes fails to decrease (Tab.1). Although most of newly generated wastes is fed back to recovery processes, still about 1.6 million Mg per year are neutralised by dumping.

Table 1

Wastes from coal extraction accumulated over the years 2004÷2007 [million Mg][2]

	Years			
	2004	**2005**	**2006**	**2007**
Total	36.77	36.37	36.5	36.79
Treated by recovering processes	35.15	34.56	32.5	33.89
Neutralisation – dumping	1.57	1.68	2.45	1.64
Temporary stored	0.05	0.13	1.55	1.26
Accumulated	548	543	517	506

The greatest deal of mining wastes falls to wastes from coal washing and treatment that are made up of rocks extracted together with run-of-mine and then separated by means of various treatment processes applied to minerals (e.g. screening, disintegration, washing, flotation) as the average contribution of such wastes in the total amount of wastes usually reaches about 88%. The past studies proved that coal wastes demonstrate properties that enable numerous applications in such sectors as:

- civil engineering for erection of hydrotechnical and engineering structures
- production of building and fireproof materials
- agriculture as fertilisers or substrates
- power engineering, where recovered coal can be combusted in boilers as a fuel (coal slurry) with a low calorific value
- mining, as filling and sealing material for engineering jobs.

A substantial part of foregoing wastes falls to coal slurry that is produced by coal treatment plants of hard coal mines. The slurry contains coal with the finest granulation, where particle size is always below 1 mm and the contribution of particles with their size less than 0.035mm is sometimes as high as 60% of the total coal content. Depending on quality parameters (ash and sulphur content, calorific value) the slurry can be either directly added to fuel mixtures offered to power plants or can be deposited in sedimentation ponds of individual coal mines. The present study deals with slurry provided by the "Piast" Hard Coal Mine that generates substantial amounts of slurries, which is shown in the graph below (Fig. 2)

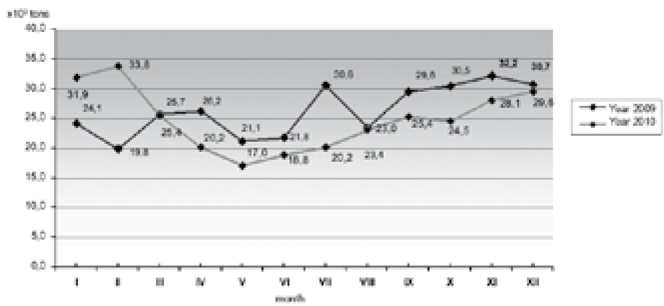

Fig. 2. Production of coal slurry

According to available information, the foregoing slurry is utilised in the following way:

- 72% is deposited as wastes
- 24% is sold as blends with steam coal
- the remaining amount is passed on to employees or sold to individual customers.

Admixing of coal slurry to steam coal that is sold to power plants is profitable but consistence of raw slurry is a drawback. Very high surface humidity of the material that reaches sometimes as much as 25 to 30% makes problems with unloading of blends from railway cars, in particular in winter time due to lack of sufficiently cheap antifreeze agents. The slurry grades with the granulation class of 0.1 mm with admixture of water-soaked clay makes a suspension that is very steady and water separation from such a mixture is virtually infeasible. Examples of typical parameters demonstrated by slurries are summarised in Table 2.

Table 2

Specifications of coal slurry

Hard Coal Mines	Jas-Mos	Piast	in New Zealand
Water content [%]	34.9	25.5	40
Calorific value [kJ/kg]	11,935	8,327	25 MJ/kg
Ash content (for slurry ready for use) [%]	30.25	41.4	<4.5
Sulphur content [%]	0.71	0.88	

This study focused its attention on slurry grades supplied from the 'Piast' Hard Coal Mine as the new plant for the slurry granulation was designed right for that coal mine. The research program was intended to find out such a technology and operation parameters of the equipment to achieve transportability of the final, i.e. disintegrated and granulated product at the level quite similar to coal dust. It will enable to accomplish high degree of granulate dispersion in coal and facilitate preparation of steam coal blends. The studies on the granulation process were carried out with use of two devices: a chute vibration granulation machine (a granulation chute) and a disk granulating machine. Hydrated lime and burnt lime (CaO) were used as a binding agent.

Research test

The chute vibration granulation machine (a granulation chute)

The first tests were carried out with use of a laboratory granulation machine with a vibrating chute self-designed by the AGH University (Fig. 3).

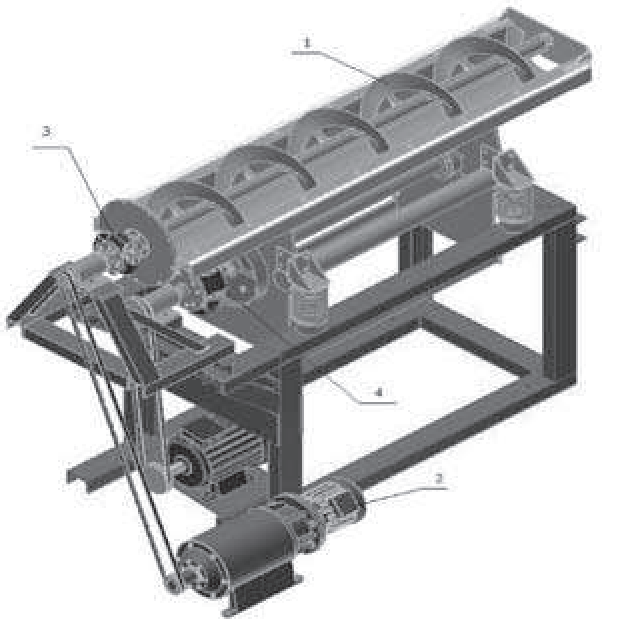

Fig. 3. Granulation machine with a vibration chute [6,7]

The supplied coal slurry was used to make samples with the weight of 1 kg each. All samples were first disintegrated and then appropriate amounts of hydrated lime were added. Operational parameters of the granulating machine were determined on the past experience [3÷5].

The first experiment was carried out for reference purposes where samples of coal slurry were subjected to granulation with no admixture of binder. The outcome product for that test is shown in Figure 4. The granulate obtained from that experiment exhibited much undesired distribution of grain size since even very large grains with the diameter of above 50 mm were spotted with very wide spread of sizes. (Fig. 4). The reason for such an outcome was very high transient moisture, reaching about 26% that entails clustering of material into large amorphous lumps when tests are in progress. Therefore it proved necessary to add a dedicated agent that is capable to bind a portion of moisture contained in slurry. The obtained granulate demonstrated high plasticity and tendency to clustering, which disqualified the final product for further utilisation.

Fig. 4. The granulate obtained from the coal slurry provided by the Hard Coal Mine 'Piast' and produced with no admixture of a binding agent

The first binding agent that was applied was hydrated lime since it is easily available and cheap. Hydrated lime was admixed to coal slurry for the following purposes:

- improvement of the granulation process (with decreased humidity) for raw pellets which leads to increased uniformity of pellet sizes
- increase in the pellet crushing strength after drying (seasoning)
- prevention from pellet cracking while heating and increase in the thermal shock temperature.

The experiments were carried out for 1, 2, 3 [%] content of lime, i.e. 10, 20, 30 [g] correspondingly. (Fig. 5 a, b, c).

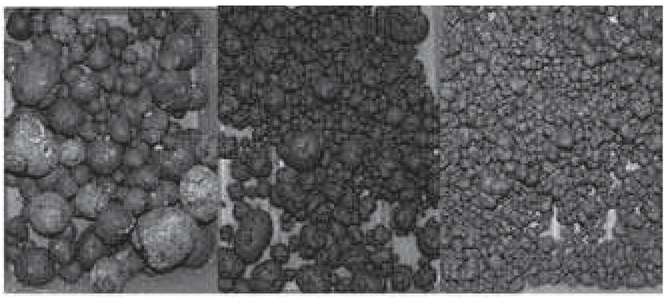

Fig. 5 Granulate produced from the coal slurry with the admixture of hydrated lime at an amount of: a) 1 % w/w of coal slurry b) 2 % w/w of coal slurry c) 3% w/w of coal slurry

The material produced of a sample that contained 10 g of hydrated lime exhibited better granulation structure than the ones that with no admixture of binder (Fig. 4). The size dispersion for the obtained pellets was slightly narrower with less moisture, plasticity and tendency to clustering. However, the final product of the pelletising process failed to meet the expected requirements (Fig. 5a).

Even better results were achieved for granulation of a coal sample that contained 20 g of hydrated lime (2% of coal slurry w/w), the effect of which is demonstrated in Figure 5b. The final product exhibited much smaller size of pellets, lower humidity, disappearing tendency to clustering and higher crushing strength.

The granules with best properties were produced when 30 g of hydrated lime, i.e. 3% of coal slurry w/w was added to the granulation process. The final product of that process is shown in Figure 5c. The pellets feature with appropriate size with narrow dispersion, low humidity, no susceptibility to clustering and much higher crushing strength.

The foregoing results demonstrate that application of hydrated lime as binder for coal slurry brings about satisfying effects, which can be seen in Figure 5c. The laboratory test results serve as the proof that the amount of admixed hydrated lime should oscillate around 3% w/w of the granulated coal slurry.

Disk granulating machine

Since the chute vibration granulation machine failed to provide sufficient productivity (less than 10 t/h) the next attempts assumed granulation tests with use of a disk granulating machine that enables to achieve the desired productivity of 50 t/h.

For that test series the hydrated lime was substituted with burnt lime (calcium oxygen). Calcium oxygen CaO, commonly referred to as burnt lime, is produced by calcination of limestone, i.e. calcium carbonate $CaCO_3$ according to the following reaction.

$$CaCO_3 \xrightarrow{temp} CaO + CO_2 - 42.7\ kcal$$

where application of water onto calcium oxide enables to obtain hydrated lime (calcium hydroxide):

$$CaO + H_2O \rightarrow Ca(OH)_2 + 16\ kcal$$

Reaction between burnt lime and water entails substantial moisture reduction and, in addition, temperature of the entire mixture of coal slurry and lime increases, which in turn leads to further drop of slurry humidity and allows operating the plant at low temperatures.

The tests were carried out with use of a disk granulating machine designed and assembled by the AGH University itself. The machine is driven by an electric motor with the power of 2.2 kW and rotation speed of 1440 rpm. The motor with the embedded reduction gear drives a belt transmission and the torque is then applied to the disk shaft. Rotation speed of disk is controlled by means of an inverter from Siemens, where the maximum speed can reach 50 rpm. The granulating machine is provided with tilting mechanism to adjust the slope angle of the disk within the range from 0° to 70° against the horizontal plane.

The design of the disk granulating machine assembled by the AGH University makes it possible to fix disks with diameters of 400 mm, 850 mm and 1000 mm and is provided with a system of scrapers that match the corresponding disk diameter (Fig. 6).

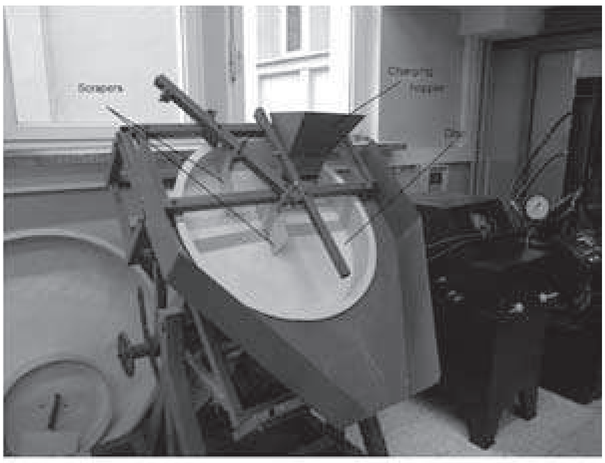

Fig. 6. Overall view of the granulating machine

Initially few granulation attempts were meant to adjust operating parameters of the machine, whilst further tests were carried out for various amounts of admixed lime.

Only the disk with the diameter of 850 mm was used for tests, where the rotation speed of the disk was set to 10 rpm and the disk slope angle was 44°. The machine operated with two scrapers.

The tests were carried out with coal slurry provided by the 'Piast' Hard Coal Mine and highly reactive burnt lime from Plant of Lime Industry 'Trzuskawica' was applied as binder and the moisture-adsorbing agent. Lime parameters are specified in the Quality Control Certificate No. Nr/04/2010 (Fig. 7).

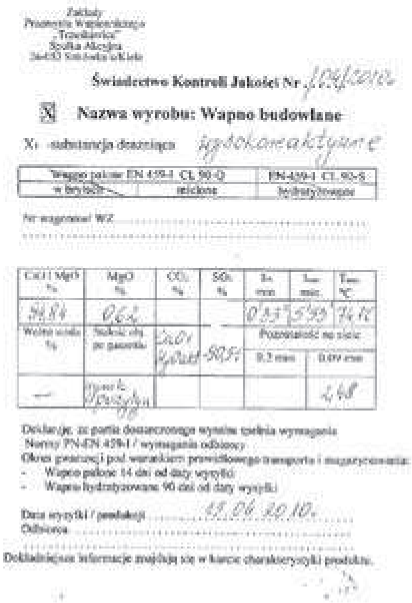
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Fig. 7. Certificate for the lime

Tests with use the disk granulating machine involved larger samples than in the previous case, with the weight of 1.7 kg. The first tests was carried out with the admixture of 8.5 g of lime, which was 0.5% w/w of the coal slurry to be granulated. The obtained pellets are shown in Figure 8-1. For that case the amount of admixed lime was insufficient, which resulted in premature escape of moisture from pellet interiors onto their surface and sticking of slurry to the walls of the granulating machine disk. The produced granulated material had high moisture content, which was reflected in its high plasticity and inclination to clustering, which disqualifies it as the material for further applications.

The second sample was made of slurry with admixing 17 g of lime, which made up 1% w/w of the coal slurry. The obtained pellets are shown in Figure 8-2. The completed investigations demonstrated that the amount of lime was sufficient and enabled correct course of the granulation process. The material was transformed into acceptable pellets and did not stick to walls of the granulating machine disk. The obtained pellets demonstrated better granulation parameters that those produced with admixture of lime at the amount of 0.5% w/w of coal slurry. The dispersion of pellet size was also lower alike the humidity, plasticity and tendency to clustering.

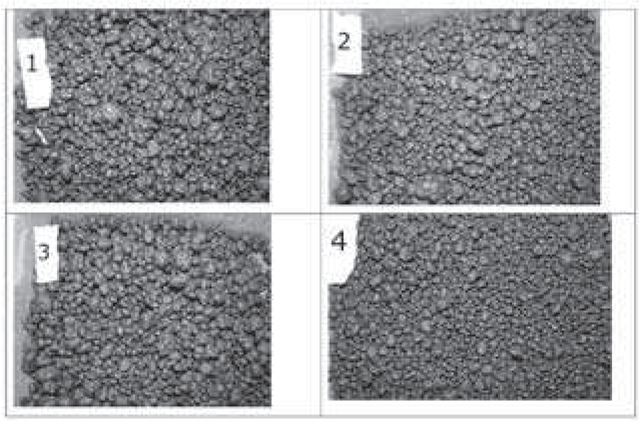

Fig. 8. Granules produced of the coal slurry provided by the 'Piast' Hard Coal Mine with admixture of burnt lime at the amount of: 1) 0.5 % w/w of coal, 2) 1,0 % w/w of coal, 3) 1.5 % w/w of coal, 4) 2,0 % w/w of coal

For the third sample of coal slurry as much as 25.5 g of lime was added, which made up 1.5% w/w of the coal slurry to be granulated. The obtained pellets are shown in Figure 8-3, where the granulation parameters of the obtained material were quite similar to the ones from the second test. Granules were of appropriate size with the narrow size dispersion, low moisture content and no tendency to clustering, which, similarly to the sample No. 2 are approving factors for widespread application of such products.

The largest amount of lime, i.e. 34 g was added to the fourth sample, which made up 2% w/w of the coal slurry to be granulated. The obtained pellets are shown in Figure 8-4. The analysis of the granulate demonstrated that the final product is too fine-grained and pellets failed to increase their diameters in spite of prolonged residence time inside the granulating machine.

Conclusion

The completed investigations make it possible to infer that coal slurry is eagerly transformed into pellets on a disk granulating machine. Burnt lime as a binder and simultaneously a moisture-adsorbing agent performs its role very well and is a better solution than hydrated lime. Contribution of lime ranges from 1% to 1.5% w/w.

The examination comprised also grain distribution in the final product (Fig. 9). The analysis of customer requirements indicates that they prefer the product with the highest possible content of grains with their size from 5 to 10 mm. Excessively fine grains entail dusting of the stuff whilst grains with too large size are poorly blended with steam mixtures of fine coal supplied to power stations as fuel.

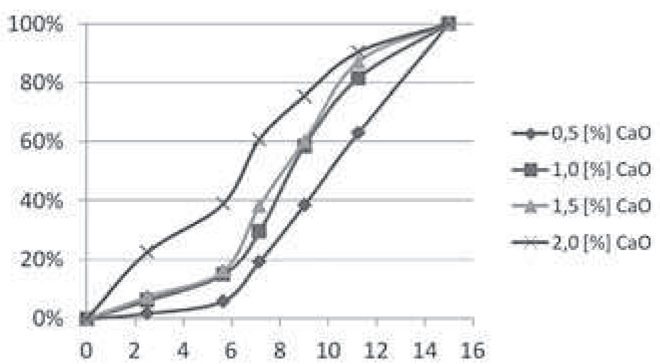

Fig. 9. Grain size distribution in obtained final granulated products

In terms of size distribution the best results were achieved for test samples No. 2 and 3, i.e. containing 1% and 1.5% of CaO.

Determination of appropriate amount of binder, i.e. burnt lime admixed to coal slurry needs more extensive test on the industrial scale with use of a granulating machine prototype. However, even laboratory tests results serve as the foundation to state that the amount of admixed lime should range from 1% to 2% w/w of coal slurry to be granulated and substantially depends on moisture content in the feed (coal slurry).

The use of burnt lime in order to reduce amount of water in coal slurry destined for pelletising seems to be fully justified. Amount of binder is pretty low, whilst active calcium (Ca) contained in the mixture shall favourably react with sulphur during combustion and bound it into an insoluble compound.

Under industrial conditions one has to take into account that the mixture shall be intensely heated, which leads to evaporation of water. It is why industrial field tests must be carried out under various ambient conditions in order to determine how much lime must be added with respect to the specific ambient temperature. For the anticipated plant with productivity of 50 tons/h the expected hourly consumption of CaO (burnt lime) shall range from 500 kg to 800 kg, but the maximum capacity of the lime feeding system should also consider abnormal moisture content of slurry and high humidity of ambient air. It is why the overall capacity of the equipment for the lime feeding system should be designed with the productivity 2-3 times higher (2t/h) with the option of infinite adjustment of the feed rates. The capacity of storage reservoirs must enable undisturbed operation of the plant during 20 hours as the minimum. The suggested solution consists in application of two reservoirs with capacity of 18 m^3.

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