

Perspective directions of the development of hydrotransport gravity mixers installations in the light of existing industrial solutions

Marcin Popczyk

Faculty of Mining and Geology, Silesian University of Technology, Akademicka 2,
44-100 Gliwice, Poland

marcin.popczyk@polsl.pl

Abstract. For fire prevention Polish hard coal mining has used mixtures of ash and water liquidshilts made on the basis of fine-grained energy wastes, which task is to fill free spaces by minimizing the possibility of oxygen access from mine air. The hydromixtures is prepared in surface mixer installations and gravitationally transported by a pipeline system to underground workings. Considering the availability of fine-grained energy waste in the immediate vicinity of hard coal mines, it should be assumed that this type of fire prevention will be successfully used in the future. The effectiveness of this method depends primarily on the efficiency and optimal operation of the mixing plant. The paper presents the evolution of mixing systems used in the last decades in hard coal mines with the division into generations, as well as the prospective directions of their development.

1. Introduction

Exploitation of hard coal in Poland is inseparable from the occurrence of many threats. One of them is the threat of endogenous fires arising in the caving goafs created after the exploitation of the longwall system. The reason for these fires are coal residues, which are often in contact with oxygen in the mine air and heat up and, after a while, they become a process of slow burning. One of the methods of limiting this type of threat is the use of fire prevention consisting in introducing into the cavity space hydraulic ash and water hydromixtures using gravitational hydraulic transport in pipelines. The flow of water jets in this type of installations is a self-steering process. This means that flow parameters such as performance or hydrotransport velocity result mainly from the spatial layout of the installation route, in particular from the ratio of its length to the difference in the height of the inlet and outlet from the installation [1, 2, 3]. In addition to the shape of the pipeline route, hydrotransport performance is also affected by the parameters of the water mixtures, such as the density and viscosity resulting from the proportion of water to fine-grained material (fly ash). If the pipeline route is shaped, as the ratio of its length to the height difference of the inlet and outlet increases, the flow parameters of the backfilling mixture decrease, which results from the drop in the flow velocity. To ensure stable flow conditions of the mixture, the installation should be characterized by the so-called correct hydraulic profile, i.e. in which the pressure height line does not intersect the hydraulic profile of the installation [2]. Otherwise, the flow of the mixture in the installation is disturbed and in the extreme case it is impossible. The standard parameter defining the consistency and the "transportability" of a liquid mixture is pourability [4]. On the basis of practical experiments and multiple measurements



verified both in laboratory and industrial conditions, it can be stated that mixtures intended for caulking gullets (voids characterized by small dimensions) should have spreading in the range from 180 mm to 220 mm, and mixtures intended for filling voids of large dimensions, especially those having the character of a self-extinguishing filling, should have a smaller leveling in the range from 140 mm to 180mm [5].

Increasing the level of the mixture is achieved by increasing the proportion of water in the mixture. The effect of increasing the proportion of water in the mixture is to reduce the concentration of solids in the mixture, reduce the density of the mixture, lower the viscosity, and increase the setting time, deteriorate the strength properties of the solidified mixture, and in extreme cases even the loss of solidification. From the point of view of hydrotransport, the mixture with lower concentration of solids ensures lower resistance of flow in the installation, and thus provides higher flow velocity and a greater range of transport - which is important especially in the case of a significant horizontal distance of works from the filling shaft or a small level difference between the surface and the place of carrying out the filling works. In the caving goafs, the mixtures with the greater leveling provide greater penetration and better filling of the goaf, especially in the case of small porosity [2, 4].

On the other hand, the high leveling mixture contains a much larger amount of water than can be bound by fly ash contained therein, which drains into underground workings and additionally charges the mine drainage system. Therefore, the most important element in the correctness of carrying out the process of hydraulic fluid handling and transport is an exact mixer system that performs a mixture of water with specific rheological parameters [1].

2. Characteristics of the hydrotransport gravity installation

Currently, suitable gravity hydrotransport installations on hard coal mines in Poland are used to make hydraulic backfill or hydromixtures of ash and water. The hydraulic stowing is a mixture of water and sand with the possible addition of crushed gangue and its main purpose is to protect the surface from the effects of underground mining on the surface. The hydraulic stowing can also be used for making filling jacks and eliminating headings[2, 6]. Currently, due to the lack of longwall excavations using hydraulic backfilling, this direction of gravity installations should be considered historical and non-development and is not analyzed in the paper.

The second direction of the use of gravity installations is the production of ash and water mixtures in them, which are the material for such mining technologies: fire prevention, reconstitution of caving goafs, liquidation of excavations, making jacks, solidified fill. The basic materials used in such installations are fine-grained energy wastes, coal slimes and flotation wastes. The efficiency and correctness of the operation of the mixing and pipeline transport system depends on the following elements [4]:

- limited hydrotransport coverage (length of the route),
- the level of homogeneity of the mixture,
- dosing accuracy of ingredients,
- minimization of dewatering,
- the possibility of dosing and mixing of different fine-fraction waste.

Most of these elements are associated with the mixing system used in the surface part of the installation, therefore the method of dosing and mixing individual components is the key from the point of view of the process correctness. In the last few decades, mixing installations producing fine-grained liquid water mixtures have evolved from the simplest, to a very small extent, controllable mixing systems, to the currently highly advanced dosing, monitoring and mixing systems realized with the use of full industrial automation. Table 1 shows the development of mixing plants for fine-particle materials with water over the last decades divided into generations.

Table 1. The evolution of mixing systems of fine-particle materials in recent decades in Polish hard coal mines.

Generation	Mixer type	Feeding to pipeline	Pipe diameters (mm)	Automation, sensorisation, dosage	Feeding with fine-grained material
I	Flow (tubular, counter current)	gravitationally through the wash hopper of the hydraulic filling plant	185	No full control	Tank trucks, rail tankers
II	flow (tubular, counter current)	Gravitational through: - the wash hopper of the hydraulic filling plant - to a pipeline led out to the surface	185	No full control	Tank trucks, rail tankers Storage silos
III	One- and two-shaft mixers	Pumping through an intermediate tank	Shaft 185 Workings 150	Manual water control, visual assessment of density	Tank trucks, railway tankers in cooperation with retention silos
IV	One- and two-shaft mixers	Pumping through an intermediate tank or directly	Shaft 185 150 Workings 150	Automatic dosing control based on the densometer	Retention silos
V	Duo installation. Combined fine-grained and sand mixing system	Variable layout: - feeding the hydraulic backfill by gravity - a fine-grained mixtures by pump	Shaft 185 150 Workings 150	Full measurement automation: - density - flow rate - pressure	Large storage retention silos, surface storage of sand

3. Mixing systems of fine-particle materials with water

Among the used systems of mixing dry fine particles with water can be distinguished:

- counter-current,
- flow,
- flow with the use of a rotor pump,
- special mixers using a feed pump.

3.1. Counter-current mixing system

One of the first systems of mixing fine-grained materials with water in order to obtain a hydromixture was the so-called mixing system. "Counter-current" or "direct" (figure 1). The fine-grained material (fly ash) was pressed directly in a pneumatic way using compressed air from cement cars or cement wagons to the inlet of the transport pipeline with simultaneous water supply. Pre-mixing occurred at the point where the dry material meets the water and then the mixing process proceeded during the flow in the transport pipeline. Such a mixing system was characterized by low emergency design and a

simple operating principle. The basic disadvantage of this system was the lack of possibility to control the density and level of homogenisation, and the efficiency of work depended only on the experience of service staff. The guarantee of trouble-free operation of the installation was the administration of significant quantities of excess water to underground workings. An additional disadvantage was the feeding of significant amounts of air into the pipeline, which disturbed the laminar flow of the water mixtures, causing pulsation and hydraulic impacts during the flow in the pipeline.

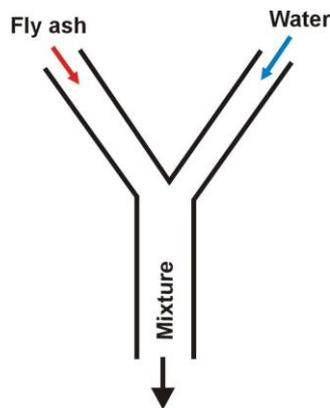


Figure 1. Counter-current mixing system.

3.2. Flow mixing system

Another type of mixing systems used is a flow mixer, whose cross-section and view was shown in figures 2, 3 and 4. The operating principle of the mixer consists in feeding the dry material (fly ash) pneumatically from cement cars or cement wagons directly to the mixer. In the mixer, the ash flow is through the perforated section of the pipe through which the water under pressure in the outer coat of this section gets. The mixing takes place on a longer road than in a counter-current mixer and the outgoing hydromixture has a homogeneous character immediately after leaving the mixer. The efficiency of the mixer depends on the pressure of the feed water and the amount of pneumatic delivery of dry fly ash.

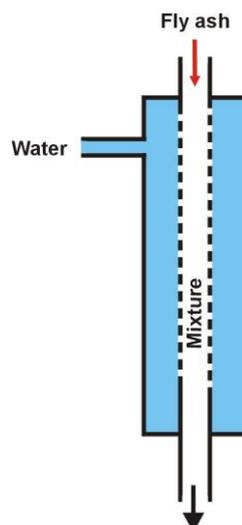


Figure 2. Flow mixer using a water coat.

Increasing the efficiency of the hydromixture feeding is realized by parallel installation of several sets of such a mixer as in figure 3. This solution allows simultaneous unloading of several cement cars or cement tanks.



Figure 3. Built-up set of four flow mixers.

The main advantage of this device is its mobility and simplicity of design, which allows its use also in field work. The example of this application can be liquidation by filling with fine-tuning hydromixtures surface sites as in figures 4 and 5.



Figure 4. Flow mixer built-up in the field.



Figure 5. Place of feeding of fine-grained mixture to the surface.

3.3. Flow mixing system using an impeller pump

In the case of using a mixer installation away from the place of feeding to the vertical part of the pipeline installed in the gravity transport shaft, it is necessary to mix and pump the liquid mixture. In this case, mixer systems equipped mostly with rotary pumps adapted for hydrotransport of granular materials of the PH or HC series are used (figure 6). This solution allows for a high degree of homogenization of the water mixtures, reduction of the amount of excess water, obtaining a high-density consistency and the use of components dosing control systems.

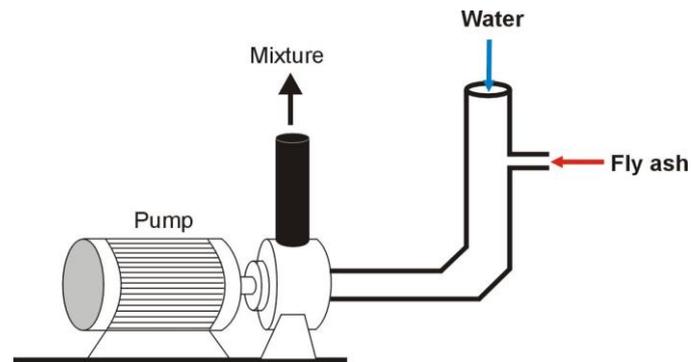


Figure 6. Mixer system using a rotary pump.

3.4. Special mixer system using a feed pump

The currently built installations for small-fraction hydromixtures are based on ensuring the appropriate quality of the produced water mixtures in terms of density, consistency and minimization of excess water. In addition, these installations are based on the addition of dry material to the mixer from retention tanks and not directly from car tanks or wagon cisterns.

Such systems ensure:

- accuracy of homogenisation of the mixture,
- dosing accuracy of ingredients,
- the possibility of using process automation,
- reduction of operating costs of the installation,
- rational water management,
- the ability to create mixtures for current technological needs,
- low investment costs for container installations,
- elimination of a significant amount of air from hydromixtures in comparison to flow installations.

The system operation process is divided into two stages: the mixing stage and the feeding stage for the hydrotransport pipeline. The mixing system is based on a high-efficiency mixer, usually with screw construction, working in a continuous cycle. The ready-mixed liquid mixture coming out of the mixer is usually stored in a storage reservoir before it is injected into the transport pipeline. The feeding system is equipped with a screw pump or a rotor pump that draws in a hydromixture from the retention tank and feeds it into the transport pipeline. The use of a retention tank allows to eliminate disturbances in the operation of the installation due to the different efficiency of the mixer and the pumping system. Examples of such an installation are shown in figures 7-9.



Figure 7. Retention tanks for fly ash.



Figure 8. Screw mixer.



Figure 9. Hydromixture's retention tank.

The use of mixer systems with the use of feed pumps allowed for full automation of the dosing process and preparation of fine-grained hydromixtures with the possibility of building such a plant in field conditions as shown in figures 10-13.



Figure 10. View of the local mixer installation.

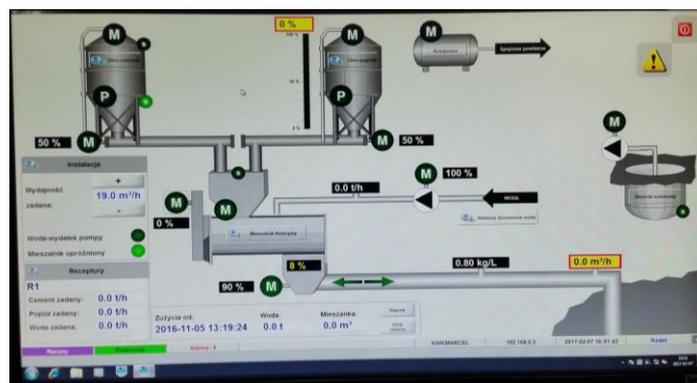


Figure 11. Installation control and monitoring module.

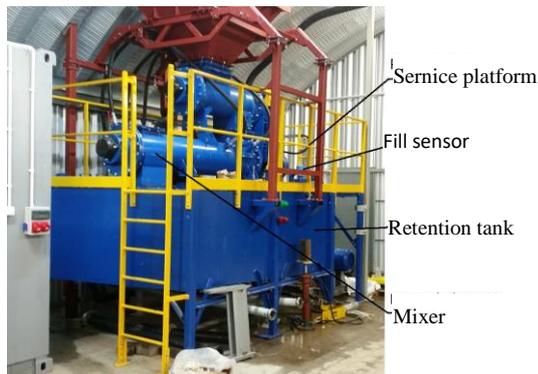


Figure 12. Elements of the mixer and feeding system.

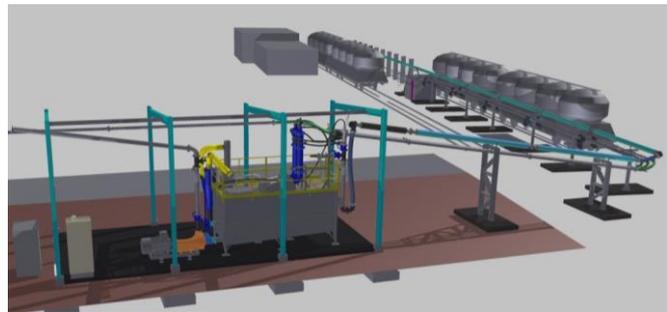


Figure 13. The virtual model of cement tank unloading station.

4. Future installations for the preparation and transport of two-phase hydromixtures

As mentioned in the introduction of the paper, installations making hydraulic backfill made of water and sand as well as grained coarse material such as mine stone are now in liquidation or used to a negligible extent mainly for the liquidation of corridor workings. However, this can be implemented only in the mine areas with access to such installations. Considering the cost of building such an installation, one should not expect such an investment in the coming years. An alternative solution is to combine a mixer installation of fine-grained materials with a mixing system of water and grained coarse material to form a so-called mixer "Duo-installation". The first such concepts and projects have already been created and will be implemented in the coming years. Below, in figures 14 and 15, a model of such an installation is shown which is divided into two modules.

The first duo-installation module that produces fine-grained liquidshare is equipped with the following basic elements:

- storage silos for ashes,
- ash transport system from silos,
- ash buffer tank,
- mixing system, along with the metering and ash feeding system,
- buffer tank for the mixture,
- mixture pump,
- hydraulic installation for feeding the mixture.

The second module of the duo-installation for the production of a water-sand mixture is equipped with the following basic elements:

- sand storage yard,
- sand bunker,
- sand screen,
- dispenser belt feeder,
- conveyor belt,
- sand washing station.

The principle of the functioning of such a duo-installation consists in the daily work of the module for preparing fine-grained hydromixtures for fire prevention, while the use of the hydraulic filling module will take place periodically, eg in the case of the need to quickly build a filling jack separating or insulating the fire region.

The capacity of the duo-installation can be estimated today for the production capacity of ash-water mixtures at the level of 120-200 m³/h, and the production capacity of the water-clay mixture up to 300 m³/h.

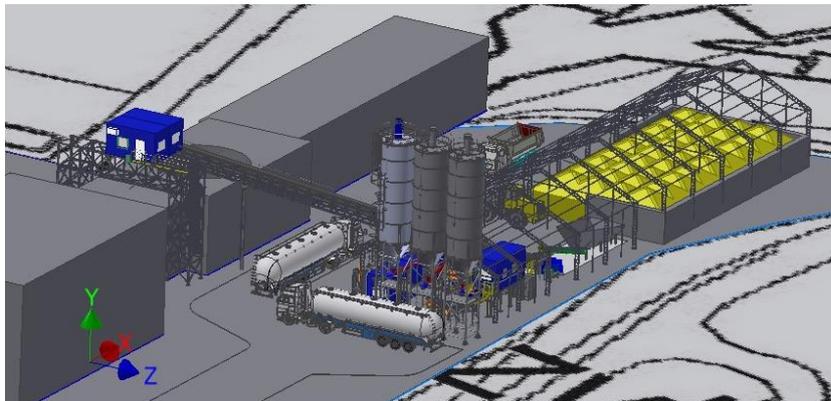


Figure 14. The view of the duo-installation model from the silo side of the fly ash.

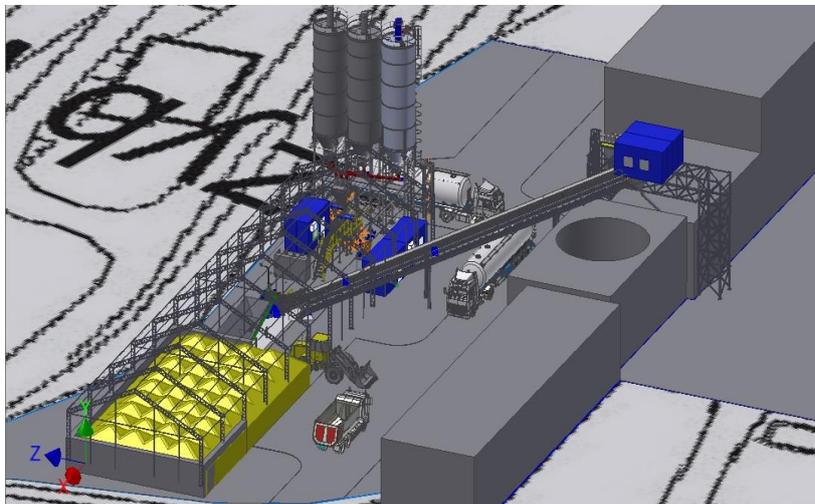


Figure 15. The view of the duo-installation model from the side of the sand storage yard.

5. Summary

Mixing installations for the production of fine-grained hydromixtures have been successfully used in Poland for several decades, mainly for sealing the infestations of active walls in the framework of fire prevention. The produced hydromixture is transported by pipelines using gravity feed systems, and its flow parameters are mainly influenced by such factors as: the ratio of its length to the difference in inlet and outlet height from the installation and density and viscosity of the water mixtures due to the proportion of water to fine-grained material (fly ash). From the point of view of hydrotransport, the mixture with lower concentration of solids ensures lower resistance of flow in the installation, and thus provides higher flow velocity and a greater range of transport - which is important especially in the case of a significant horizontal distance of works from the filling shaft or a small level difference between the surface and the place of carrying out the filling works. On the other hand, the high leveling mixture contains a much larger amount of water than can be bound by fly ash contained therein, which drains into underground workings and additionally charges the mine drainage system. The first countercurrent and flow type mixing installations presented in the paper are characterized by the simplicity of operation and service, however, the hydraulic liquid from them contains a significant amount of excess water, which increases the costs of its service and significantly impairs the mine's drainage system.

Mixer systems introduced in recent years equipped with mixers supported by impeller pumps or feed pumps allowed for full automation of the mixing process as well as the dosing system of

individual components ensuring the assumed parameters of the mixture in terms of consistency and density as well as flow parameters in the pipeline. The future of mixer systems is their version of the so-called "Duo" also includes the function of making a fine-grained mixture and a backfilling mixture made on the basis of sand and fine mine stone. An example of such a solution is presented in p. 4 of the paper. Such an installation can have a range of applications in various mining technologies, such as:

- caulking caving goafs,
- making jams and backfilling,
- liquidation of excavations with backfilling material and binding material,
- fast insulation of fire fields especially important in mines exploiting coal that is self-igniting.

The concept of duo-installation presented in the paper has the following advantages:

- accuracy of homogenisation of the mixture,
- dosing accuracy of ingredients,
- the possibility of using process automation,
- reduction of operating costs of the installation,
- rational water management,
- the ability to create mixtures for current technological needs,
- low investment costs for container installations,
- elimination of a significant amount of air from hydromixtures compared to flow installations,
- low investment costs of the module for making the water-sand mixture compared to the costs of constructing a classical backfilling plant.

References

- [1] Popczyk M 2017 The impact of changes in the rheological parameters of fine-grained hydromixtures on the efficiency of a selected industrial gravitational hydraulic transport system. *IOP Conference Series: Materials Science and Engineering* **268** conference 1
- [2] Palarski J 1997 Fill transportation and sedimentation mechanisms for stope filling 9th *International Conference on Transport and Sedimentation of Solid Particles* Kraków
- [3] Plewa F, Mysłek Z and Stozik G 1997 Parametry hydraulicznego doszczelniania zrobów zawałowych odpadami drobnofrakcyjnymi *III Szkoła Geomechaniki* Ustroń pp 2003–12
- [4] Popczyk M 2002 *Ekologiczne i górnicze aspekty przemysłowego wykorzystania odpadów energetycznych i poflotacyjnych w podziemiach kopalń* Praca doktorska Wydział Górnictwa i Geologii Gliwice
- [5] Plewa F and Mysłek Z 2001 *Zagospodarowanie odpadów przemysłowych w podziemnych technologiach górniczych* (Gliwice: Wydawnictwo Politechniki Śląskiej)
- [6] Palarski J 1981 *Hydrotransport* (Warszawa: WNT)
- [7] Różański Z, Suponik T, Matusiak P, Kowol D, Szpyrka J, Mazurek M and Wrona P 2016 Coal recovery from a coal waste dump. *E3S Web Conf.*, **8** 01052 DOI: <http://dx.doi.org/10.1051/e3sconf/20160801052>
- [8] Wrona P, Różański Z, Pach G, Suponik T and Popczyk M 2016 Closed coal mine shaft as a source of carbon dioxide emissions *Environmental Earth Sciences* **17(15)** DOI:10.1007/s12665-016-5977-7