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**THE IDEA OF THE RECOVERY OF MUNICIPAL SOLID WASTE INCINERATION (MSWI)  
RESIDUES IN KŁODAWA SALT MINE S.A. BY FILLING THE EXCAVATIONS  
WITH SELF-SOLIDIFYING MIXTURES**

**KONCEPCJA ODZYSKU ODPADÓW Z INSTALACJI TERMICZNEGO PRZEKSZTAŁCANIA  
ODPADÓW KOMUNALNYCH (ITPOK) W TECHNOLOGII WYPELNIANIA WYROBISK  
SAMOZESTALAJĄCYMI SIĘ MIESZANINAMI W KOPALNI SOLI „KŁODAWA”**

In view of the permanent increase of the municipal solid waste incineration (MSWI) residues amount, the numerous attempts to find a way of their recovery have been undertaken. In this paper the idea of the recovery of the MSWI residues in Kłodawa salt mine is presented. The idea is to fill the waste in underground workings, close and/or backfill the underground excavations with self-solidifying mixture prepared on the basis of MSWI grained solid residues. Two techniques are proposed: 1) hydraulic backfill technique (HBT) where the mixture is prepared in the surface installation and pumped down into the underground workings through shaft and the pipelines and 2) dry waste technique (DWT), where dry grained waste is dropped into the mine by pneumatic pipeline transport, then supplied to the underground mixture-preparing-installation and pumped as a thin liquid or paste into the selected workings. The description of the technology is preceded by general characteristic of the hardening backfill in underground mines and by characteristic of MSWI residues, drafted on the basis of the literature review.

**Keywords:** waste recovery, hardening backfill, Kłodawa salt mine, MSWI residues

Wobec stale przyrastającej ilości odpadów wtórnych pochodzących z instalacji termicznego przekształcania odpadów komunalnych (ITPOK) poszukuje się sposobów ich odzysku i unieszkodliwiania. W artykule przedstawiono koncepcję technologii odzysku odpadów ITPOK w Kopalni Soli „Kłodawa”. Polega ona na wypełnianiu, likwidacji i podsadzaniu wyeksploatowanych wyrobisk samozestalającą się mieszaniną sporządzoną na bazie droбноziarnistych odpadów stałych pochodzących ze spalarni odpadów komunalnych. Zaproponowano dwie technologie: 1) technologię podsadzki hydraulicznej (TPH), w której mieszanina jest przygotowywana w instalacji powierzchniowej i jest dostarczana poprzez szyb do wyrobisk kopalni rurociągiem oraz 2) technologię suchego odpadu (TSO), w której odpady z powierzchni transportowane są pneumatycznie rurociągiem do kopalni, następnie dostarczane są do podziemnej

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instalacji przygotowania mieszaniny, po czym mieszanina jako płynna ciecz lub gęsta pasta jest przepompowana rurociągiem do docelowych wyrobisk. Opis koncepcyjny technologii poprzedzono ogólną charakterystyką utwardzanej podsadzki w kopalniach podziemnych i odpadów z ITPOK opracowaną na podstawie przeglądu literatury.

**Słowa kluczowe:** odzysk odpadów, podsadzka utwardzana, kopalnia soli „Kłodawa”, odpady ITPOK

## Introduction

The civilization development, modern economy and technology all involve the generation of an increasing amount of waste. Environmental concerns on the one hand and the growing deficit of many raw materials on the other – both require a smart and effective method of waste management. Detailed regulations regarding this problem are included in European law and national laws.

Under the Act on Waste (2012) there is a specific hierarchy of waste management activities. Art. 18 states that “...*Every person who undertakes activities resulting in the creation or potentially resulting in the creation of waste, [...] should as the first priority prevent or limit the creation of waste as well as their negative impact on the life and health of persons as well as the environment at the stages of product manufacturing, during and after its use*”. If waste creation could not be prevented, the owners is required to recover it. Waste recovery involves the preparation of waste by the owner for repeated use or recycling. If this is impossible due to technological constraints or it is not ecological or economically justified, owner should arrange for other recovery processes.

In this act “recovery” is construed to mean: “*any process, where the main results that the waste serve a useful application by replacing other materials, that would have been otherwise used to fulfil a particular function or as a result of which the waste are prepared to serve such function in a given plant or generally in the economy.*”

Neutralisation means subjecting waste to biological, physical or chemical transformation processes in order to reach at the state which does not create a threat to life, human health or the environment (Act on Waste, 2012).

Hierarchical waste procedure, Fig.1, begins from the most favoured option – reducing waste generation, and goes through reuse, recycle, recovery and disposal of waste to landfills – as the least favoured.

Underground mining technologies often use different waste material as a component in backfilling mixtures. This is primarily residue material from mineral processing in plants as well as various industrial fine-grained waste (e.g. flying ash, bottom ash). The waste is used as a filling material mostly in the hydraulic backfilling technology. The profits are:

- lower costs of backfilling and post-exploitation space liquidation,
- stabilisation of excavations by utilisation of waste material supporting properties,
- protection of underground mine structure,
- improving of work safety,
- protection of the surface against deformation,
- reduction of landfills area.

One of the waste types commonly generated in Europe are municipal solid waste incineration (MSWI) residues. The management of MSWI residues becomes one of the very important problems in many countries and numerous attempts to find a way of their effective use are

undertaken. The problem becomes a very important one in Poland: in view of the construction of the new MSWI plants in our country, a dramatical increase of the MSWI residues amount is expected in the upcoming years. In response to the problem of management of this waste in Poland, a main goal of the study was to develop a concept how neutralise the waste in the mined out areas of the “Kłodawa” Salt Mine and in the process – recover the waste as a material used to backfill and improve the stability of mine workings and to liquidate redundant post-exploitation voids with the self-solidifying backfilling technology. In order to develop an objective concept several areas of study were considered:

- backfilling technologies with waste recovery,
- German experience with MSWI residue recovery and storage in salt mines,
- MSWI residues characteristic as a material for backfilling mixture,
- geological and technical conditions in Kłodawa salt mine,
- idea of technologies possible for MSWI residues recovery in Kłodawa mine.

In this work the authors present the idea of MSWI residues recovery for mining techniques in Kłodawa salt mine in Poland, on the basis of the experience with hardening backfilling in underground mines and the waste recovery techniques in German salt mines.

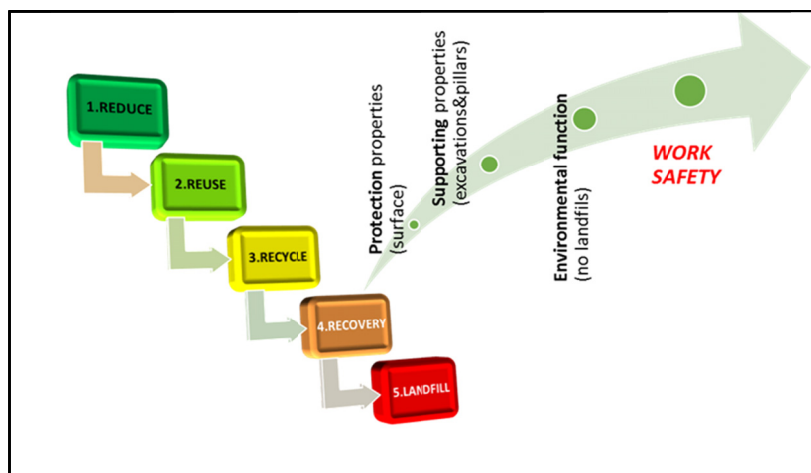


Fig. 1. Waste recovery scheme within the hierarchy idea

The waste recovery process in underground mining technology, is based on three fundamental and important features/properties of the waste which can be usefull, Fig. 1:

- protection against surface subsidence,
- supporting properties improving underground excavations stability,
- environmental function based on elimination or reduction of residues landfills area.

Finally all the above result in improvement of underground work safety and ecosystem.

Different utilisation of underground salt caverns, among others, are connected with gas storage technology after leaching process, where the critical problem is based first of all their stability affecting tightness of the caverns, (Wang at al., 2018).

## 1. Backfill technologies with waste recovery

There are numerous backfilling technologies using waste, applied in order to support and/or liquidate post-exploitation excavations. The technologies described in this chapter are considered by authors as the most interesting for waste recovery in a salt mine. They are: paste technology and backfilling technologies applied in German salt and potash mines for waste recovery. Both technologies are characterized by lack (or minimal) effluents, due to bonding all liquid used for transportation of backfilling material.

### 1.1. Paste backfilling

The technology of a cement paste backfilling was created and applied for the first time in 1970s and 1980s in Canada, Germany, South Africa and the USA. It was developed for ore mines, with milling tailings (floatation waste) from processing plants used as a backfilling material (Crandall, 1992). Currently, the paste backfilling has gained popularity in the mining industry. It is a new and developing technology that combine waste management with goaf filling. The paste backfilling is a heterogeneous mixture of processing waste, water and a binding agent. Solids constitute 70 to 85% of the mixture, the added binding agent – form 3 to 7% by weight (Sheshpari, 2015). The mixing liquid can be clean water or contaminated mine water. After binding and seasoning, the paste backfilling can reach the desired (design) strength performance in underground mining, preventing excessive rock mass deformation. Compared to the typical hydraulic backfilling, the main advantages of paste backfilling are the possibility of hydraulic transportation with complete (or almost complete) binding of water. There is, therefore, no need to gather and pump out the excess water from the backfilling. In time, the backfill solidifies (binds), creating a solid mass with compressive strength of several to more than a dozen MPa. The backfill mixture can be made with many ingredients. The main ingredient is dried mill (floatation) waste from ore processing plants or filter deposits combined with a binding agent: Portland cement, granulated metallurgical slag, flying ash. In order to improve the transportation conditions of the backfilling mixture and its flowing properties, other additives are used. The composition of the backfilling mixture is designed to correspond to individual conditions and requirements, including: type of waste, type of binding agent, chemical and granular composition of the solid matter, chemical composition of water, ability of the backfill mixture to be transported hydraulically, binding time, strength of the backfill, etc. Currently, studies are being conducted on the possibility to use not only processing waste, but also other fine-grained waste material in the backfilling.

### 1.2. Waste recovery experience in backfilling technique

In Germany, mine workings in potash mines have been backfilled with waste material stored in massive amounts on the surface spoil tips since the beginning of the 20th century. The waste material is refuse salts from potash processing (Bodenstein et al., 2001). Other types of waste have been used as backfilling ingredients since 1990s. In 2002, the European Court of Justice accepted the use of waste for backfilling mining goafs as a method of waste recovery (Schade, 2008). In the same year, in Germany, several legal acts allowed hazardous waste in the backfilling to be placed but only in rock salt and potash mines, if there is a possibility to permanently isolate the harmful material from the biosphere. Currently the underground storage and recovery

of thermal waste treatment residues (including municipal waste) for mining technology purposes is an important solution applied for decades in more than ten underground mines in Germany (Alwast et al., 2012). According to German law, two types of waste location in underground mines can be discerned:

- underground storage site (Untertage-Deponie) and
- waste recovery in mining technology (Untertage-Verwertung).

In the recovery process, the waste is used directly as a backfilling material or included in backfilling mixtures in order to reinforce mine workings, improve their stability and, in consequence, protect the surface of the mining area. For the most part, the waste is located in rock salt and potash mines (Schade, 2008). In 2010, the total amount of flying ash and flue gas treatment residue from waste-to-energy plants used in Germany to backfill salt mine workings exceeded 1 million Mg (Salamon, 2015). Several location and recovery methods are used. One of them is the self-solidifying hydraulic backfilling technology and paste backfill (Dickstoffversatz).

The backfilling is composed of fine-grained materials mixed with brine and, sometimes, a binding agent and other additives to create a fluid or semi-fluid mixture suitable for pipeline transport. The use of brines with different salt concentrations instead of water in the mixture prevents salts from dissolution. The mixture pumped into the working solidifies, completely or nearly completely binding the liquid. Materials used to make mixtures are: ash and slag, dusts from filters, solid residue from flue gas treatment in waste-to-energy plants, ash from the incineration of sewage sludge, etc. This type of backfilling is used, for example, in the Unterbreizbach potash mine in the Werra district. The mine started the extraction of potash in 1910. Since 2005 it is connected by output haulage systems with the Hattorf-Wintershall mines (Behnsen, 2008). The mine extracts a bedded deposit of Zechstein potash at the depth of 700 m and deeper. Part of the deposit was extracted using the room and pillar method. Currently, the stability of workings is at risk. The underground waste utilization plant was established in 1992. The waste, such as ash, volatile dusts and flue gas treatment residues from waste-to-energy plants are used to make a backfilling. The waste is delivered to the mine by silo trucks and pneumatically transferred to stationary silos. Then, it is also pneumatically transferred by pipelines into underground silos. From there, the material is supplied to the backfilling preparation system: the waste material is mixed with a salt solution in accordance with the patented formulation and worked into a thick suspension – paste. The paste backfill is hydraulically transported to fill workings where it solidifies and binds the liquid completely. The annual performance of the plant is 260,000 Mg (K+S Entsorgung GmbH, n.d.).

### 1.3. Waste from the waste-to-energy plant characteristic

Thermal treatment of municipal waste is a common neutralisation practice in Europe. Even 10 years ago, approximately 20-25% of all municipal waste collected in Europe was treated with thermal processes (Integrated Pollution Prevention and Control, 2006). The most common thermal treatment technology is incineration. The waste-to energy plants generate secondary waste (residue) in the amount of approximately 27% of the initial waste mass. Solid waste types include:

- waste directly generated by the thermal treatment, i.e. bottom ash and slag,
- boiler ash,
- flying ash and other waste generated by flue gas treatment.

Bottom ash and slag are created in the amount of 200-350 kg per 1 Mg of incinerated municipal waste (20-28.5%) and flying ash: 20-40 kg/Mg of waste (2-4%) (Integrated Pollution Prevention and Control, 2006). The residue waste from waste-to-energy plants are categorised as group 19 in the waste catalogue (Regulation of the Minister of Environment, 2014).

The waste contains permanent organic pollutants (e.g. PCB, PCDD) and is enriched in heavy metals compared to municipal waste. The content of harmful substances in the secondary waste is variable and depends highly on the types of waste incinerated. Pollutants are not evenly distributed in consecutive stages of waste generation. The least amount of organic pollutants and heavy metals is present in the bottom ash, the most – in fly ash and flue gas treatment products. It is, however, thought that not just the amount of pollutants is important, but also their ability to migrate into the environment. Therefore, the classification of waste as hazardous and nearly all regulations pertaining to waste storage or recovery are based on the leachability test.

Testing of the composition of the residue from waste-to-energy plants and leachability tests for the waste itself and its processed form are pursued in many scientific institutions throughout the world. Their purpose is not only to find safe methods of waste management: recycling, recovery or neutralisation, but also to learn to what degree the waste can be a source of critical materials.

Bottom ash and slag are usually not categorised as hazardous waste, which is the reason why, in Western Europe, they are stored on surface landfills and recovered as special purpose material in civil construction. Flying ash and flue gas treatment products are qualified as hazardous and require storage in hazardous waste sites. Prior to that, they are sometimes subject to various processing methods, e.g. stabilisation, vitrification or acid metal extraction. In Germany, this type of waste is stored or utilised in salt mines (CEWEP, 2012) (chapter 2).

## **2. A concept of MSWI residue recovery and neutralisation in the self-solidifying backfill system for the “Kłodawa” Salt Mine**

Currently in Poland, a concept for the recovery and neutralisation of the residue from municipal waste thermal treatment in the backfilling technology used for the mined out workings of the “Kłodawa” S.A. Salt Mine is created (Korzeniowski & Poborska-Młynarska, 2016).

In order to apply this concept, geological and technical basic requirements must be met:

- tight rock mass in the mine providing long-term insulation of the backfilling material from the underground water horizons,
- required capacity of underground mine workings,
- efficient technology for waste recovery.

The first two requirements are met in the Kłodawa mine. The “Kłodawa” mine was established in 1949-50 and for over sixty years has been mining rock salt from the salt dome composed of the Zechstein salt formation rocks. The Kłodawa salt dome is a part of the huge salt structure Izbica Kujawska-Kłodawa-Łęczycza occurring in Central Poland. The mine is located in the central part of this structure. The mining area is 8 km long and around 2 km wide. Rock salt beds occurs on the average depth of 250 m. The deposit consists of rock salt and zuber salts mainly which are the rocks with proven impermeability.

The mine is accessed by three shafts at three main levels, at the depths of approximately: 450 m, 600 m and 750 m (Fig. 2). The exploitation takes place in several mining fields under the protection of safety pillars preventing the water inflow into the mine workings. Every mining field is divided into inter-levels 25 and 30 meters high. The inter-levels are separated by protective shelves with a minimum thickness of 10 m. Chambers are excavated parallel or perpendicularly to the strike direction of salt layers, in accordance with the geology of the mining field. The perpendicular chambers are separated by pillars of 15 m or wide.

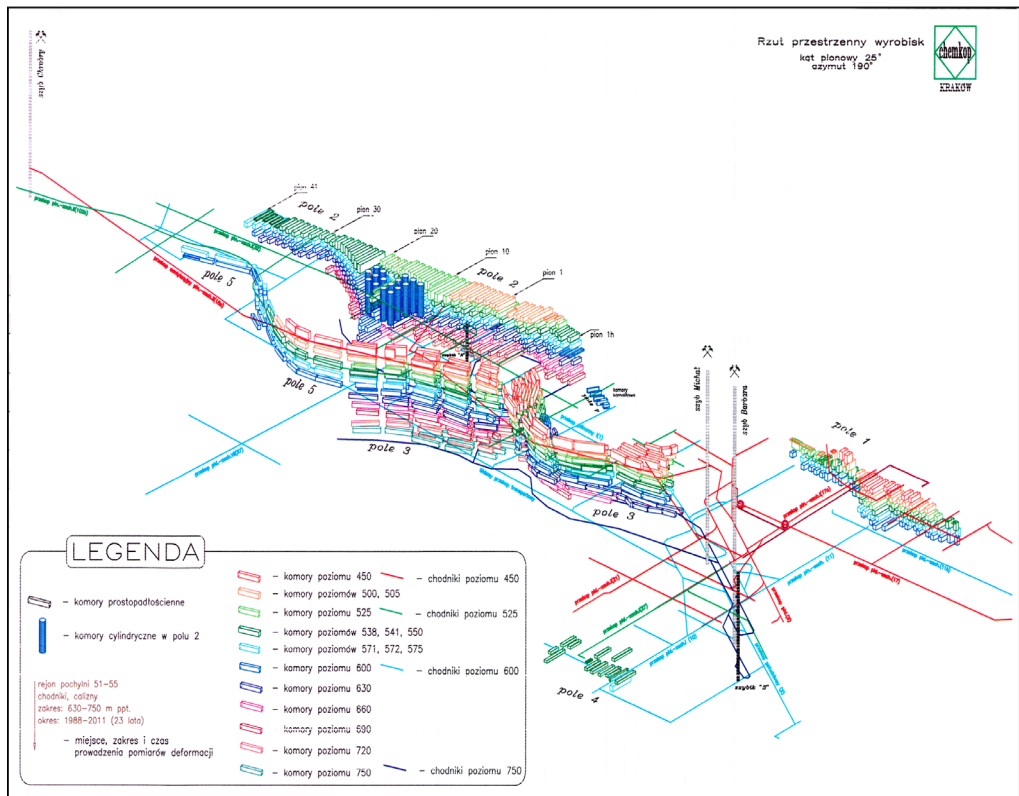


Fig. 2. The structure of mine workings in the Kłodawa salt mine (Archival materials of the KS "Kłodawa" S.A.)

Currently, the primary mining method is the room and pillar system, in which the salt is extracted by chambers of rectangular cross sections, with dimensions changing together with the depth and geology of the deposit. Dimensions of typical chamber are: width 15-12 m, height 15-13 m, length 100-150 m and more. The example of the developing chamber is presented in the Fig. 3. The extracted salt chambers are not filled, meaning that the total volume of the excavations in the mine is over 18 million m<sup>3</sup>. The chambers exhibit a long-term geomechanical stability. Abandoned workings are distributed in several mining fields, which creates the possibility to separate the backfilling area without interfering the salt extraction.

The total water inflow into the mine is small, created by local brine occurrences and a small shaft waters inflow. There is no drainage network in the mine.



Fig. 3. Salt chamber in „Kłodawa” Salt Mine, a part of the panoramic view  
(Photo: J. Wrzak) (Poborska-Młynarska, 2013)

The concept of the MSWI residues recovery for the backfilling technology in the Kłodawa mine combines the shared features of several technologies from the fields of underground mining and waste management – it is a process for workings backfilling, liquidation and waste neutralisation. The main goals of the process are:

- improving the condition of the rocks mass by supporting of roofs and pillars in the chambers, resulting in decreased deformation rate of workings and the surface within the mining area,
- liquidating the mined out workings,
- limiting the area of surface landfills, with a benefit for the environment.

It is also a process of waste recovery with mining technologies and waste neutralisation by placing it in a sealed rock environment, isolating the harmful substances from the biosphere.

Considering the geology of the deposit and technical possibilities in Kłodawa mine, the basic requirements for the backfilling technology applied in Kłodawa mine has been specified as follows:

- the backfilling of workings will improve the rock mass stability in the mining fields,
- the backfilling process will not deteriorate the hydro-geological conditions in the mine,
- the backfilling process will not cause contamination of the mine environment,
- the backfilling process will not interfere with salt production,



- the backfilled area will be eventually effectively long-term isolated by the tight rock-mass and technical measures,
- the effective backfilling and liquidation of a huge underground voids needs the efficient pipeline mass transport.

In a view of the presented requirements and technical feasibilities in Kłodawa mine and considering the mining industry experience in waste recovery for backfilling technology the most beneficial resolution is hardening backfilling, with two kinds of the self-solidifying backfilling mixture: thin liquid and thick paste (Fig. 4). Both mixtures consist of the fine-grained dry residues of MSWI, binding material, other compounds and brine. The brine use instead of fresh water prevents salt from leaching of in the backfilled rooms.

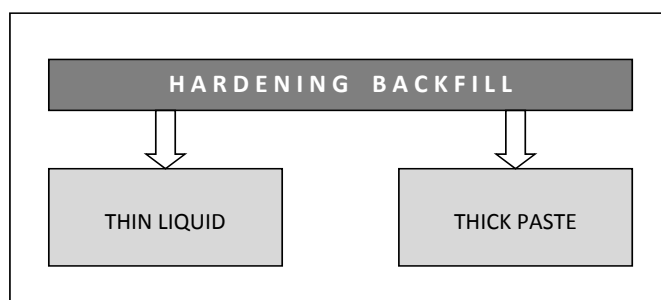


Fig. 4. Types of proposed self-solidifying waste mixtures

There are two technological lines: for backfilling mixture preparation on the surface and underground.

The first technology of the hydraulic backfill technology (HBT) is dedicated to the thin-liquid mixture. The mixture is prepared in the surface installation and then supplied underground directly into the target individual chambers through a system of pipelines (Fig. 5, 6).

The second technology – dry waste technology (DWT) consists in underground preparation of backfilling mixture from dry components, formerly transported pneumatically from the surface by pipelines, into the selected underground preparatory chamber, where a liquid mixture is prepared for further transport by pipelines into target chambers (Fig. 5, 7). This technology concerns paste backfilling mixtures.

The advantage of the first method is the mobility of the system, allowing to supply substantial portion of the mixture to multiple chambers by successive extend of underground installation. The disadvantage is: a surface location of the mixture-preparing installation (environmental impact) and a long-distance pipeline transport. Clogging of the backfilling pipeline due to the solidification of the material during necessary technological downtimes can cause a major problem.

The second method is advantageous due to the fact that the mixture preparation system is located underground – this excluded the environmental problems, reduces the length of transport routes and enables the operation of the system in proximity to the filled workings. The disadvantage is the need to organise additional space and infrastructure underground for mixture preparation and the lack of possibility to use the hydrostatic pressure of the liquid created by depth, in order to facilitate transport.

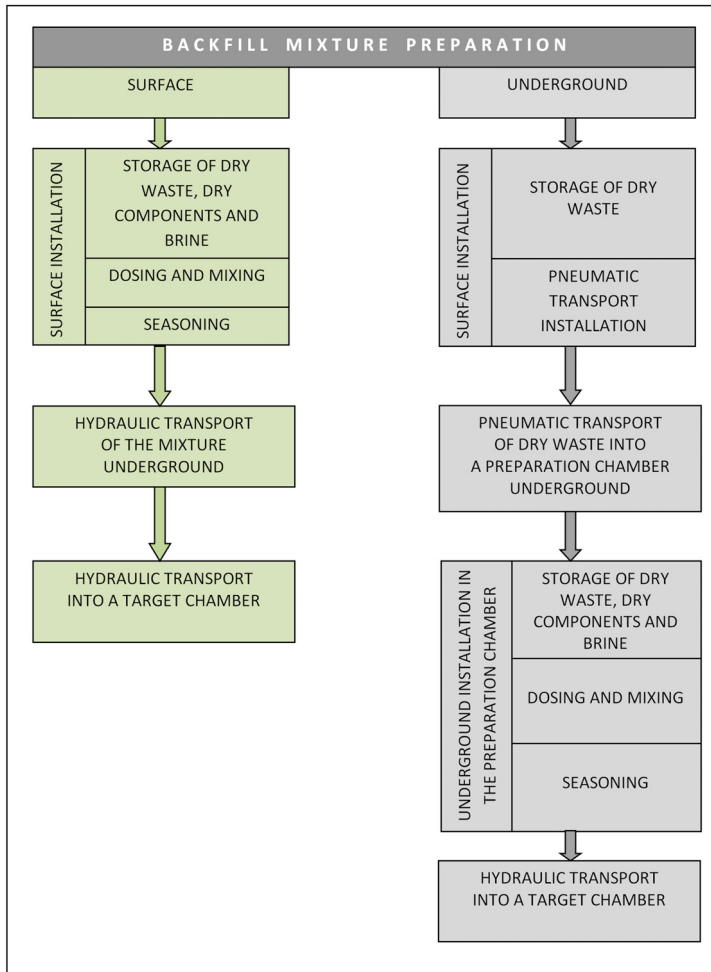


Fig. 5. Backfilling mixture preparation and transport scheme

The composition of the mixture must be experimentally developed for the specific type of waste, taking into account a number of requirements such as: the quantity and quality of allowed pollutants, grain composition, binding time, strength after binding and transport conditions.

The concept of the system for the recovery of waste incineration plants residues in the Kłodawa mine includes the construction of surface and underground facilities, different for each technology. For the HBT, the surface infrastructure includes in general:

- silos for bulk material (waste, binding agent, other components),
- water or brine tanks,
- loading/discharge infrastructure,
- mixer installation,
- deaeration system,
- control equipment.

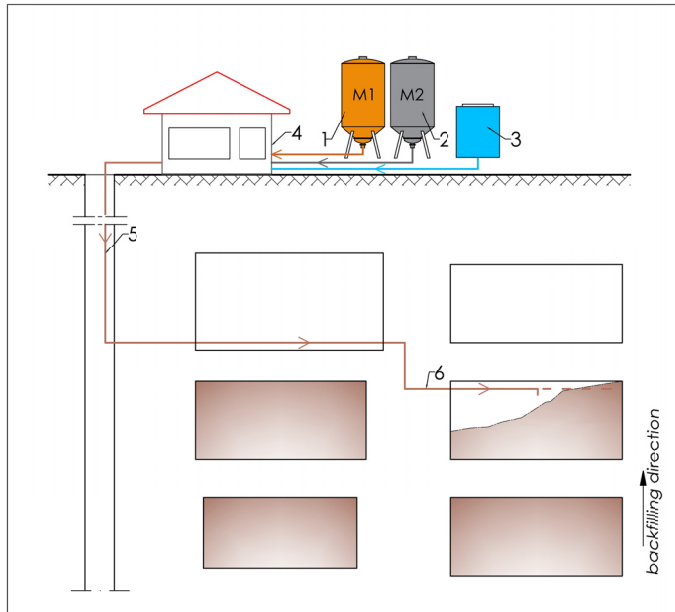


Fig. 6. Idea of hydraulic backfill technology (HBT) based on mixture prepared in the surface installation and provided through mine shaft to individual target chambers

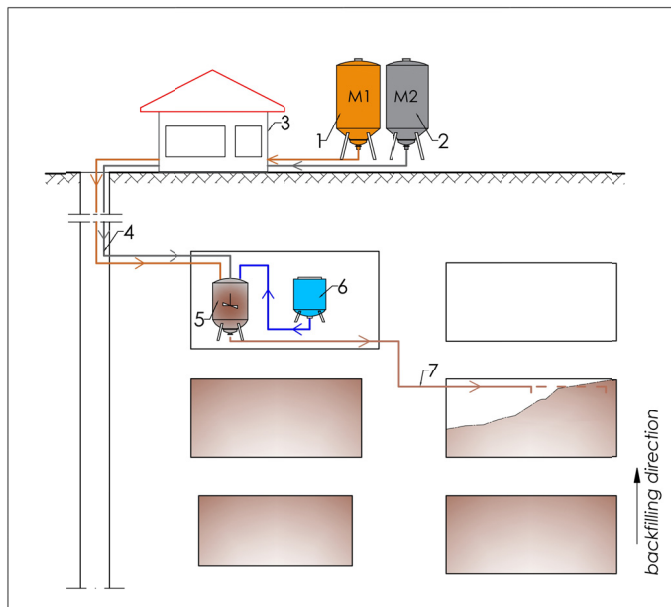


Fig. 7. Idea of Dry Waste Technology (DWT) with dry components provided from surface silos by pneumatic transportation through mining shaft to the mixture preparation chamber, followed by placement into target chambers

The underground infrastructure includes:

- shaft pipeline,
- shaft inlet systems,
- intermediate pumps, chamber reloading installation,
- preparation equipment in chambers,
- chamber insulation dams,
- underground environment monitoring devices (sensors, network, control system, etc.).

The main difference between DWT and HBT is the transportation media utilized in the pipeline system, respectively: compressed air or brine and location of final preparation place of the mixture (on the surface or underground).

### 3. Conclusions

The studied concept for the recovery of MSWI residues for the technology of self-solidifying backfilling in the “Kłodawa” Salt Mine is an efficient proposal of a technological solution that is new in Poland. This is an extremely important issue, particularly against dramatically increased amount of the municipal solid waste incineration (MSWI) residues recently and in upcoming years. Similar technologies have been positively verified in salt mines in Germany.

Placing waste in mine workings with the application of the self-solidifying backfilling technology is, according to the authors, the most beneficial solution for the geological and mining conditions of the Kłodawa mine. This also solves the problem of waste water management for effluent brines, uncontrolled migration of effluents in the deposit and uncontrolled leaching of the workings. Waste recovery by placing it as a bonded mixture in mine workings, in a tight rock mass, is also a physical neutralisation of the waste.

The described technology requires the preparation of appropriate backfilling mixture formulations. The concept provides a management solution for a continuous stream of waste generated in the amount exceeding 400,000 Mg/year and soon much larger than that, due to the construction of new waste-to-energy plants in Poland (Korzeniowski & Poborska-Młynarska, 2016).

Kłodawa Salt Mine with its structure and underground workings is an appropriate place where some waste (MSWI residue) properties can be recovered. The proposed concept assumes recovery of very useful waste properties which will result in:

- improvement of the stability of underground mine workings,
- reduction of undesirable rock mass deformation,
- reduction of the surface subsidence,
- elimination of environmentally unfriendly surface landfills,
- expected commencement of the process of systematic liquidation of the mine,
- replacing another material which would be alternatively used as a backfill,
- dramatically reduction of the mine liquidation costs in the future.

Placing of waste in a sealed salt rock mass, providing protection and insulation from underground water and the biosphere instead of storage in surface landfills is beneficial for the environment in an obvious way.

Kłodawa Salt Mine facilities allow the waste recovery can be associated by its simultaneous neutralisation in safe, isolated and naturally sealed underground space.

## Acknowledgements

The research were supported by the AGH University of Science and Technology in Kraków, statutory work No 11.11.100.005.

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