USE OF MULTI-BARRIER WATER-PROOFING SYSTEM FOR THE CONSTRUCTION OF UNDERGROUND WASTE DEPOSITS

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ABSTRACT

Due to excessive burdening of the Earth's surface, a large specific population density in Slovenia and a negative attitude among the inhabitants, it is becoming increasingly difficult to acquire new sites for surface waste deposits. The demand for the use of and depositing of waste materials in underground sites has therefore increased. By depositing waste materials into underground sites, their negative influence on the landscape and the Earth's surface are prevented or eliminated, the Earth's surface is kept undamaged and full protection of the deposit site from atmospheric influences is ensured. With environmentally friendly mining it is possible to return all waste materials which are obtained during excavation, separation, enriching and processing of mineral and energy raw materials to excavated underground sites. By implementing the concept of multi-barrier systems for waste depositing it is possible to ensure its safe deposition into underground sites. The preparation of waste materials and the technique for their deposition into underground sites should be adapted to the conditions in individual underground deposit sites.

INTRODUCTION

Large amounts of waste materials which are obtained during the excavation, separation, enriching and processing of mineral raw materials have no market value and as a rule have been deposited in poorly organised and inexpensive surface waste deposit sites. However, surface waste deposit sites occupy the Earth's surface, distort the landscape and have a negative influence on the environment (dust, seepage waters, radon, etc.).

The large specific population density in Slovenia, a negative attitude and mistrust among the inhabitants, a lack of efficient administrative and professional organisation, poor legal regulation and the consideration of economic principles present a large problem in the acquisition of new sites for surface waste deposits.

The share of underground sites used for permanent deposition of waste materials is on the increase, especially since the introduction of the multi-barrier system for deposition. Hazardous and radioactive waste is deposited into abandoned salt mines and other mines; underground waste deposit sites for radioactive waste are set in magmatic rock (granite), waste materials are also used in active mines as reinforcement and backfilling materials. Especially in coal mines, fly ash from thermal power plants, heating plants and incineration plants is used as backfilling material in order to increase the stability of underground sites and reduce the influence of mining work on the surface.

UNDERGROUND WASTE DEPOSIT SITES

The Law on Environmental Protection defines waste deposit sites as places or facilities on or below the Earth's surface which enable a safe and controlled final or temporary deposition of waste without endangering the health of people or the quality of water and air or ecological conditions outside the site or the landscape, with the use of protective measures enabled by the best technology which has been tested in practice.

The following can be used as underground waste deposit sites:

- active mines
- abandoned mines
- mines undergoing closure
- newly constructed underground waste deposit sites

With the use of excavated underground sites in active mines, high construction costs can be avoided, but the method for their preparation and procedures for depositing waste materials in them must be harmonised with the excavation technology, which additionally limits the type of waste materials suitable for deposition in active mines.

The advantages of depositing waste materials in abandoned mines or in mines undergoing the closure procedure are low costs of construction of the underground waste deposit sites, if natural safety parameters are present.

Safe deposition of all types of waste materials is ensured in newly built underground waste deposit sites which are usually constructed in solid rock mass with a closed hydraulic ground water system.

Safe deposition of certain types of waste materials can also be ensured in fissured water-permeable rock masses with the use of appropriate technical and control measures.

Waste materials are deposited into underground deposit sites in order to

- prevent or remove negative influences on the landscape
- prevent or remove negative influences on the Earth's surface
- keep the Earth's surface undamaged
- ensure full protection from atmospheric influences
- improve stability
- eliminate the necessity during the planning of underground waste deposit sites to consider the surrounding structures and terrain configuration on the Earth's surface

The preparation and implementation of a concept for depositing waste materials are the most important requirements for ensuring safe deposition of waste materials into underground waste deposit sites. The concept of deposition must take into account the possibility of direct contact of waste materials with rock masses and ground water.

MULTI-BARRIER SYSTEM OF WASTE DEPOSITION

In constructing an underground waste deposit site it is necessary to consider the potential danger of seepage water and transport of pollutants into the surrounding rock mass or ground water. Waste materials therefore need to be pre-processed, a technical barrier system needs to be built at the site and the rock mass around the underground waste deposit site should be considered as a geological barrier system.

A multi-barrier system for the deposition of waste materials comprises the following:

- Selection and preparation of waste materials - material barriers
- Selection of technical and control measures - technical barriers
- Research of the rock mass in the surroundings of the underground waste deposit site - geological barriers

A multi-barrier system for the deposition of waste materials firstly means that the waste material itself is prepared prior to deposition, such that the pollutants are immobilised, secondly, that appropriate technical and control measures are used for the protection of underground sites, and thirdly that the underground site is located in a geological medium which does not allow contact of possible seepage water with ground water. In addition, there is always a possibility to adopt other measures to collect seepage water and rehabilitate underground sites.

A combination of a technical and a geological barrier is used in the majority of underground waste deposit sites. One must assume the non-homogeneity of the rock mass, which cannot be studied in detail and reliably sealed.

Material barriers

Material barriers include the solidification of waste materials (cementation, vitrification, etc.) and the preparation of mixtures of waste materials for backfilling.

Waste materials are first processed (crushed, screened, etc.) and solidified into pieces of varying dimensions with the use of additives (binding agents, glass, etc.). The purpose of solidification is to reduce the volume of bulk waste. This can be deposited above all into underground waste deposit sites, abandoned mines and mines being closed.

The use of mixtures of waste materials for backfilling is appropriate above all for deposition in active mines. Mixture in the form of paste enables automated hydraulic transport, simple method of deposition (backfilling), and since it does not contain excess water which would flow into underground sites after deposition, a safe method for deposition of waste materials which does not pollute ground water.

Technical barriers

Technical barriers are widely used in the construction of modern underground waste deposit sites. Their main objective is to protect the underground waste deposit sites from ground water and to prevent the outflow of any seepage water into the surrounding rock mass or ground water. Technical barriers comprise technical and control measures.

Technical measures comprise the packaging of waste materials into suitable barrels, containers, bags, etc., and the protection of the walls of the underground waste deposit site with hydroisolation plasters, foils made of synthetic materials, etc. Packaging enables the isolation of waste materials for a certain period, simple recording, transport, temporary storage and final deposition. In order to achieve the desired period of isolation of waste materials, materials with the desired mechanical strength and resistance to different influences need to be used.

Control measures include visual and automatic detection of negative influences on the environment, such as are the production of systems for the collection of seepage water, additional sealing of the area of the underground waste deposit site and rehabilitation measures.

Geological barriers

Geological barriers must reduce or prevent the flow of ground water as the main potential carrier of pollutants. The geological barriers which determine the safety of an underground waste deposit site can be divided into the following groups of problems:

- Size and structure of the geological formation
- Lithological composition of the rock mass
- Hydrogeological conditions
- Geochemical properties of the rock mass
- Active endogenous processes
- Damage to the rock mass
- Geotechnical conditions

Rock masses suitable for the construction of underground waste deposit sites must be of sufficient volume to accommodate the site. The mass must belong to the same tectonic unit with the greatest possible constancy of structural elements. The lithological composition of the rock mass conditions its hydraulic, mechanical and geochemical properties. Clay and compact rock masses are most suitable. The hydrogeological conditions in the area of the underground waste deposit site must be such that the flow of ground water is as slow as possible. The rock mass must have a high capacity for ion exchange, which is above all determined by its mineral composition, organic matter content and reactions in the rock mass. The geochemical composition of ground water must not cause the decomposition of material, geological and technical barriers and must not enhance the transport of pollutants. Underground waste deposit sites must be located outside the main regional earthquake areas and other active tectonic phenomena. If underground waste deposit sites are located in existing mines, the damage to the rock mass, its connections with nearby aquifers, karstic phenomena, water-bearing faults, etc. need to be assessed. The geotechnical conditions comprise the determination of the stress state of the rock and mechanical and physical properties of the rock mass.

ASSESSMENT OF THE SUITABILITY OF WASTE MATERIALS

Before deciding on the method of waste deposition, the location of an underground waste deposit site, preparation of the site and the method for processing waste materials, laboratory leaching tests need to be performed on

- unprocessed waste materials
- processed waste materials.

In order to prepare an assessment of the influence of deposited waste materials on the environment, a group of researchers (De Groot G.J. et al, 1989) developed a standard leachate control test. This test comprises several procedures which are determined in detail in the recommendations of the International Atomic Energy Agency (IAEA, 1991).

The study of leachate control comprises the study of unprocessed and processed solidified waste materials. The standard leachate control test for unprocessed waste materials comprises the determination of their basic properties (particle size, humidity content, volume weight, etc.), a test for total leachable amount, and an acidity test. The standard leachate control test for processed materials comprises a test for total leachable amount and a batch test. The results of testing for total leachable amount represent leaching in the event of complete crushing of a solidified sample. However, it can be assumed with great reliability that such extreme conditions will not occur in the deposit site. The batch test simulates the conditions which would occur in the event of complete flooding of the site. The results of leachate control tests enable the research of the influence of different waste materials on leaching in order to find an appropriate "recipe" for the mixture of waste materials and additives.

The results of the leaching study are used as starting points for the determination of the method of deposition, site selection, site preparation and the extent of required construction of technical barriers.

SUITABILITY ASSESSMENT OF LOCATIONS FOR WASTE DEPOSIT SITES

In depositing waste in underground sites, the characteristics of the technical and geological barriers must be taken into account and all environmental protection requirements must be observed. For this purpose, the following studies are made prior to preparing an assessment of the suitability of locations for underground waste deposit sites:

- Pollutant transport
- Geochemical properties
- Geotechnical suitability
- Safety measures

Study of pollutant transport

In rock masses, pollutants are transported via water paths. The geological and hydrogeological conditions in rock masses at underground waste deposit sites and the properties of the waste therefore need to be well known, and the basic mechanisms of pollutant transport well understood. A mathematical model of pollutant transport is made after studying these parameters in detail using analytical and numerical methods. Such a model yields results regarding the time variation of pollutant concentration in the rock mass surrounding the underground waste deposit site.

Study of geochemical properties

The study of geochemical properties of waste materials and the rock mass comprises diffusion, precipitation, absorption, ion exchange and chemical interactions. Geochemical properties can be studied on the basis of a known composite of solidified waste materials, the results of leachate control tests and known chemical and physical properties of the rock mass into which the pollutants will be spreading. Long-term events in the rock mass can be simulated with different scenarios, even in the case of complete submerging of deposited materials.

Study of geotechnical suitability

The study of the geotechnical suitability of an underground waste deposit site includes all materials which were selected with regard to its location, available volume, isolation and hydrogeological conditions. The construction of the site and selection of appropriate technology depend on different factors such as depth, mechanical properties, geotechnical conditions and various technological requirements. These factors and the fact that the distribution of stresses and strains in the surroundings of an underground waste deposit site vary during its construction make it necessary to ascertain the geotechnical suitability of the site. The assessment methodology is similar to that used in the planing of underground sites in active mines.

Study of safety measures

Technical solutions are required in order not to expose employees to chemical and physical geotoxins at underground waste deposit sites. Appropriate technical measures should also be in place to ensure fire safety at the site.

1. 'MONO' pump
2. Electromotor
3. Mixer
4. Pipeline
5. Pressure meter
6. Density meter
7. Flow meter
8. Temperature meter
9. Bridge amplifier
10. A/D converter
11. PC486/66MHz; MS-DOS, ADC
12. Printer
13. Valve
14. Compensator
15. Frequency regulator

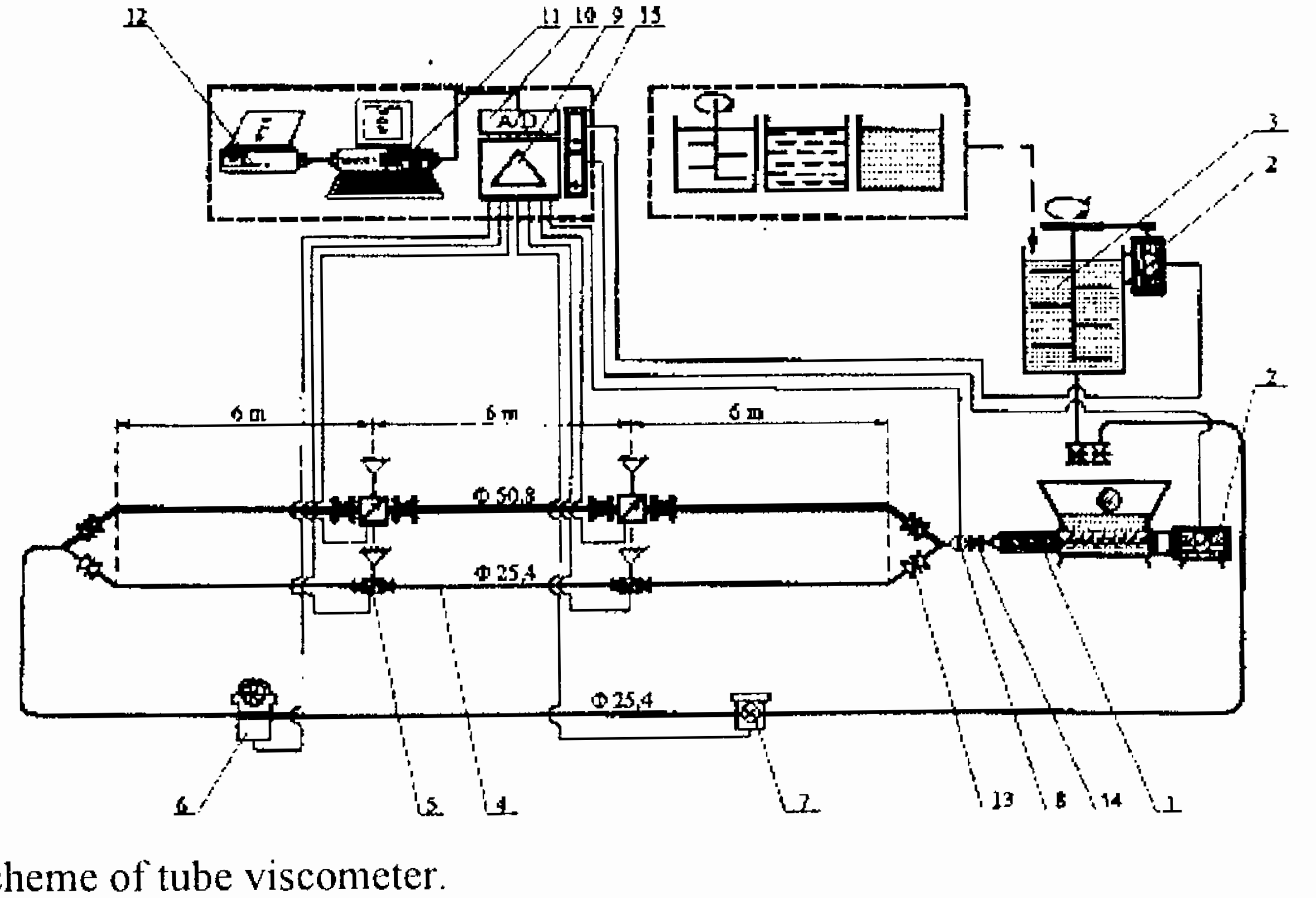

Figure 1.: Scheme of tube viscometer.

TRANSPORT OF WASTE MATERIALS

The transport of waste materials into underground waste deposit sites in active mines and in mines being closed can be performed using the existing means of transport or those which are dictated by the preparation process or the technological excavation process (study of transport characteristics). In the case of filling of excavated sites in active mines in which large amounts of waste materials are needed in order not to disturb the technological excavation process, pneumatic or hydraulic transport are usually selected.

For determination of the basic hydraulic transport characteristics we use ball viscometer and tube viscometer (both produced in-house). Ball viscometer functions on the basis of the measurement of force on a ball as it travels through a paste column (Figure 2.). Tube viscometer functions on the basis of the measurements pressure, density and velocity of flow in time when pasta travels through a pipe (Figure 1.`

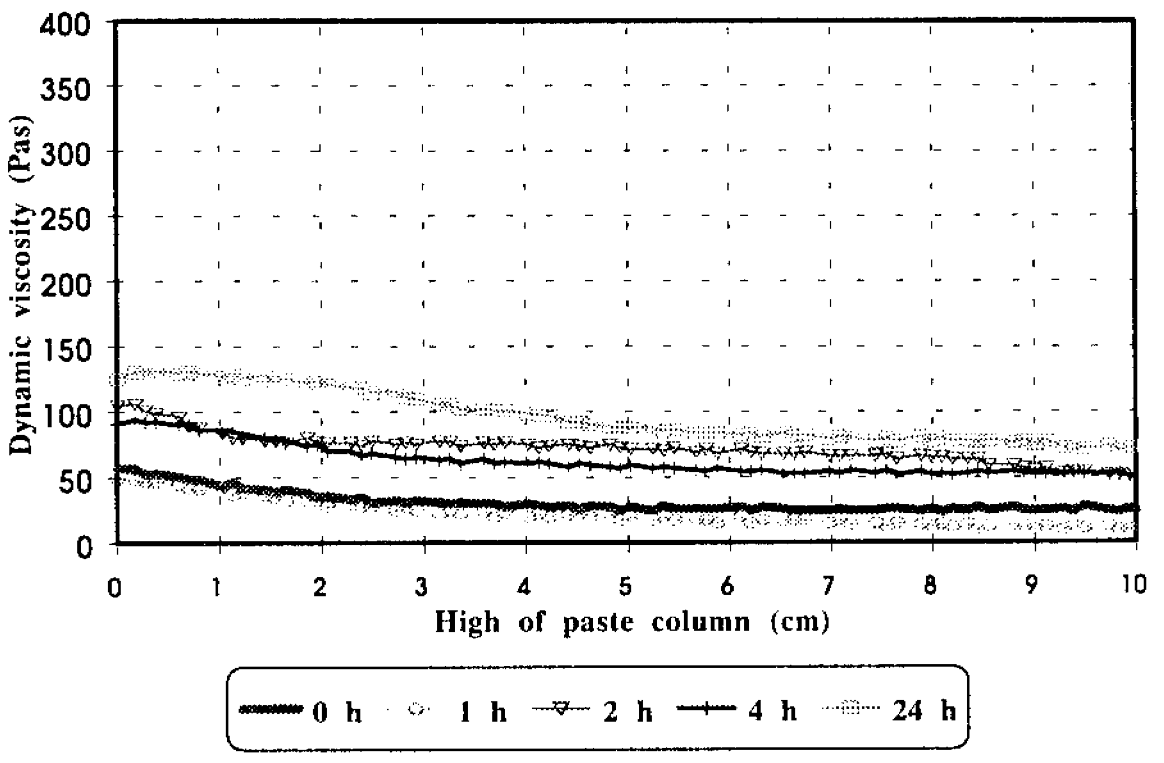

Figure 2.: Dynamic viscosity of paste as function of time (ball viscometer).

Hydraulic transport enables full automation of transport from the surface directly to the site in the mine where the waste materials are to be deposited. In the event of abandoned or newly built deposit sites, the transport system is selected with regard to the planned technology for the deposition of waste materials into the underground waste deposit site.

TWO PRACTICAL EXAMPLES OF WASTE DEPOSITION

Two practical examples of the use of underground sites for the deposition of waste materials are presented below:

- Velenje Coal Mine
- Mežica Zinc and Lead Mine

The Velenje Coal Mine is an example of deposition of waste materials in excavated sites in an active mine, which has enabled the introduction of an ecologically-technologically closed circle with both environmental and economic advantages.

The Mežica Zinc and Lead Mine is an example of deposition of waste materials in a mine which is being closed.

Velenje Coal Mine

During the production of electrical energy within the technological circle of the Velenje Coal Mine - Šoštanj Thermal Power Plant (ŠTPP), waste materials are produced which can be used for backfilling, solidification and sealing of excavated sites in the Velenje Coal Mine. The use of waste materials for backfilling in the Velenje Coal Mine has resulted in reduced sinking of the Earth's surface and a step forward towards environmentally friendly mining in the Šaleška valley.

A new method of excavation combined with backfilling is being introduced at the Velenje Coal Mine (Figure 3.). This method has both advantages and disadvantages in comparison with the formerly established method of excavation and collapsing the roof. Its advantages are a lower degree of burdening of the visible environment, reduction of surface damage, increased stability of underground sites, reduction of maintenance costs and mining damage at the sites, etc. Its disadvantages are above all increased costs of excavation and additional costs of preliminary research on the influence on the environment of backfilling with a mixture of waste materials. The economical evaluation of the method's advantages and disadvantages shows the total cost reduction.

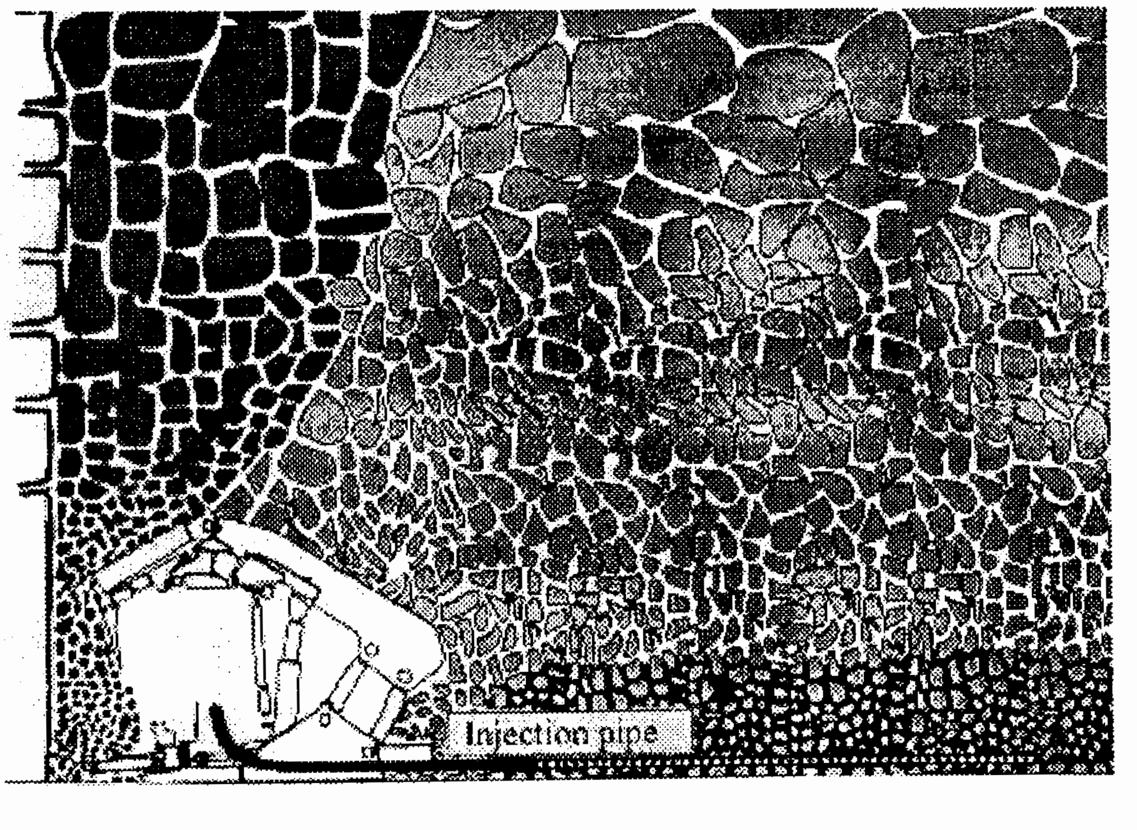

Figure 3.: New Velenje minig method combined with backfiling.

The mixture for the preparation of a paste for backfilling in the Velenje Coal Mine consists of:

- Waste materials:
- Fly ash from the ŠTPP
- Gypsum as a product of desulphurisation of flue gases at the ŠTPP
- Red mud of the Talum factory for the processing of bauxite
- Waste enamel from Gorenje

- Galvanic sludge from Gorenje

- Additives for solidification:
- Cement
- Hydrated lime

- Other additives:
- Bentonite
- Retarder C

For transport over a distance of 1 to 3 km, the paste must be stable and its pressure gradient in pumping must be as low as possible. The stability and dynamic viscosity of the paste was measured by a ball viscometer. Pressure gradient measurements were taken in a tube viscometer between pressure cells at a known distance. The necessary initial pressure was also measured. Uniaxial compressive strength was determined on paste samples after 3, 7, 8 and 60 days. Its magnitude depended above all on the amount of additives.

The standard leachate control test (IAEA, 1991) was performed for individual paste recipes. The test comprised the determination of the basic properties of individual types of unprocessed waste materials, an acidity test and the determination of the total amount of leachable substances, and a batch test for solidified paste. The results of the standard leachate control test served for the study of the influence of individual waste materials and additives on leaching in order to find the appropriate recipe for the paste.

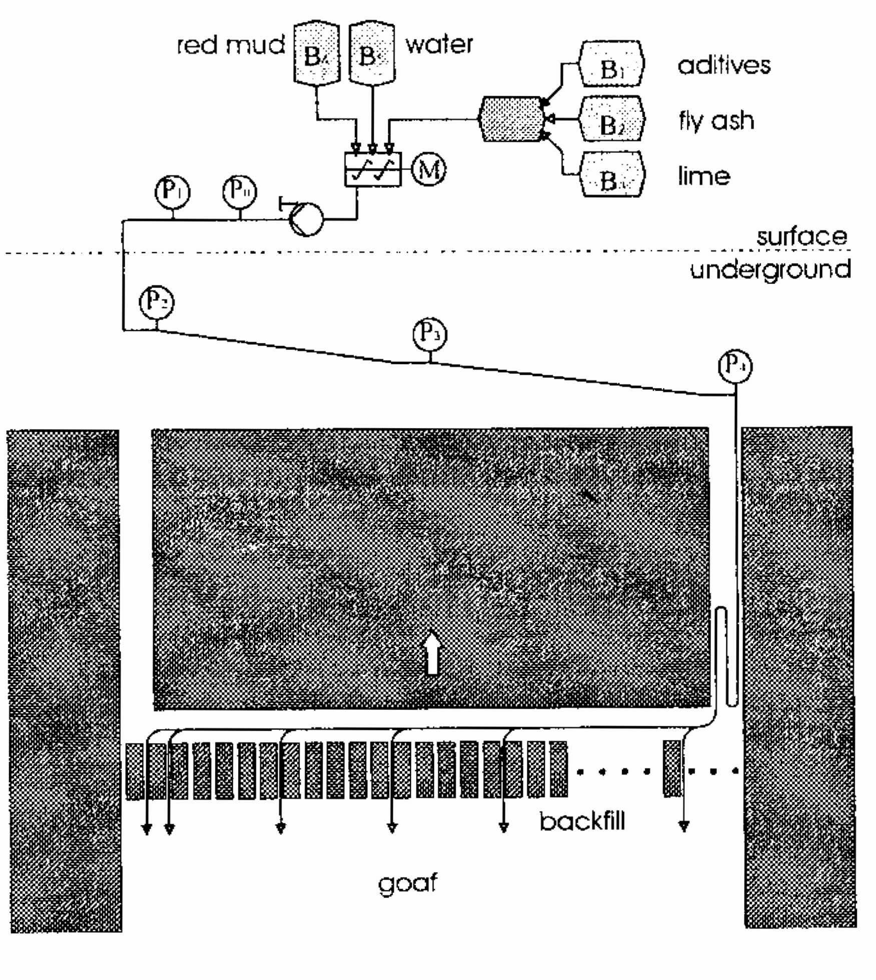

Figure 4.: Scheme of preparation, transport and backfilling of paste.

Extensive preliminary laboratory research at the Chair of Technical Mining and Geotechnology, Faculty of Natural Sciences, University of Ljubljana enabled the preparation of appropriate recipes for the mixture of waste materials for the preparation of paste. The physical, chemical and mechanical properties of individual types of waste materials and the solidified paste were also determined. In order to comply with environmental requirements, certain additives which prevent the negative influence of the paste on the environment were used for its preparation.

The procedure for the preparation, transport and backfilling of the old part of the excavated area is described below (Figure 4.); due to relatively large amounts of required waste materials, the paste is prepared with an automated mixer on the surface near the Škale shaft. It is then transported using pumps, i.e. hydraulically (continuously) to the excavated site. The paste is injected through tubes into the old part of the excavated site. Injection takes place through only one tube at a time and is repeated cyclically as the excavation progresses. The entire process for the preparation and transport of paste is managed and controlled by the process computer, through which the parameters of filling can be monitored (the use of individual types of waste materials, total amount of injected paste, amount of paste injected into individual injection tubes, etc.).

During and after filling, regular periodic emission monitoring of ground water is performed using mine piezometers in the vicinity of the old excavated part filled with paste.

Mežica Zinc and Lead Mine

In metallurgical procedures in the Mežica Mine - metallurgy, plastics production and engineering (MPI), metallurgical waste materials are produced: slag, fireproof brick and synthetic materials, the reuse and processing of which is not possible, and they need to be deposited at the site. The existing surface waste deposit site at Glančnik will be full by the end of 1997, and the mine has therefore prepared an outline project for a long-term solution for depositing metallurgical waste materials by constructing an underground waste deposit site in the Mežica Zinc and Lead Mine (MZLM). The MZLM is undergoing the procedure for closure with a developed mine infrastructure which can be used for depositing waste materials. It is planned that these will be deposited into newly excavated underground sites (silos).

In order to prepare the underground waste deposit site appropriately and to be able to select the method for its processing and deposition, the standard leachate control test was performed on unprocessed waste materials coated with cement milk, on waste materials solidified with the use of cement, and on solidified waste materials coated with synthetic materials. The tests and detailed analysis of metallurgical waste materials were performed at the laboratory of the Chair for Technical Mining and Geotechnology, Faculty of Natural Sciences, University of Ljubljana. The standard leachate control test comprised the determination of the basic properties of individual types of unprocessed waste materials, an acidity test, determination of the total leachable amount and a batch test for solidified waste materials. The final evaluation of the summary of results of the standard leachate control test showed that metallurgical waste materials covered with cement milk are suitable for deposition into underground sites with the use of technical measures for their protection from ground water.

The suitability of the location of underground sites in the MZLM for use as waste deposit sites was assessed according to the following criteria:

- sites must be located above the level which enables the drainage of mine water into the Meža river
- the area must have favourable geological and hydrogeological conditions with water-impermeable layers in the hanging wall

- the area must be stable and must have favourable geomechanical properties of the hanging wall
- control and collection of seepage water must be possible underneath the underground site
- the lowest point of the underground site must be at least 4 m below the level from which the control and collection of seepage water is possible
- the rooms must be large and their walls steep enough to enable gravitation deposition
- access to the underground site should not require major interventions
- all other activities in the vicinity of the underground deposit site should be taken into account, should they be disturbed by the deposition of waste materials
- all possible problems which could occur during the ventilation of the underground site should be taken into account

After reviewing several possible locations at the MZLM, the Graben district was selected as the most suitable.

In constructing the underground site in the MZLM, a multi-barrier system will be used for depositing waste materials. Synthetic substances will be deposited in separate silos, away from the slag and fireproof brick. The first barrier will be made by metallurgical waste materials poured with cement milk. This will mostly immobilise the pollutants. Technical measures will serve as the second barrier: hydroisolation protection of the walls of the underground site, which will reduce the possibility of flow of seepage water from the site into the surrounding rock mass, as well as inflow of ground water or surface water into the site. The third barrier is formed by the rock mass surrounding the site: the site is located in compact and compact bituminous dolomite. Due to the porosity and permeability of bituminous limestone, additional measures were planned to prevent seepage water from flowing out: sealing of the area under the site by injections, a system of boreholes for the collection of seepage water and a system for the collection of seepage water separately from other mine water into a closed circle of technological water in MPI.

The procedure for preparation, transport and deposition will be performed in the following manner: all metallurgical waste materials will be collected separately in a covered or partially covered surface storage area (deposit site). Slag will be completely cooled here and will react, while synthetic materials will be additionally dried. Synthetic materials will be transported separately from slag. The transport of metallurgical waste materials to the mine entrance at Graben will be performed by trucks in closed and covered containers. Here the containers will be transferred to mine cars and transported to the underground deposit site (silo) with the mine railway. Synthetic materials will be unloaded into silos from above, separately from the slag and fireproof brick. The metallurgical waste materials will be solidified with cement milk without excess water at the site.

During the deposition of metallurgical waste materials and after its completion, regular periodic control of the area below the underground site will be performed.

CONCLUSION

The demand for the use of and deposition of waste materials into underground sites is increasing. Due to the overloading of the Earth's surface and the negative influence of surface deposit sites on the environment, underground deposit sites are becoming increasingly important. Their construction is still expensive at present and they are therefore used only for the deposition of special and hazardous wastes.

The use of already constructed underground sites in abandoned mines, mines being closed or newly excavated underground sites in active mines represents one of the possibilities for underground deposition of waste which does not require high investment costs.

Waste materials to be deposited in underground sites must be inert special waste which has been pre-processed such that they present no long-term threat to the environment. The deposition of waste materials into underground deposit sites requires extensive preliminary research, laboratory tests and modelling, which are the basis for the preparation of environmental assessments.

It is recommended that such a technology of deposition be selected which will enable the automation of preparation, transport and depositing of waste materials.

The types of studies, research and modelling presented in the paper can serve as a guideline in the preparation of the general legislation for the construction of underground waste deposit sites.

Keywords: waste materials, underground waste deposits, multi-barrier system

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