Process Technologies for Underground Waste Storage in Manmade Cavities

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Abstract

In addition to the rock and geomechanical suitability of an underground salt cavity for use as a waste storage facility, the process technologies for conveying the waste materials from surface to underground and using them to fill the cavities are of great importance.

The technology selected depends among other things on the purpose of using waste for filling. The reason can either be to stabilise the underground structure of the mine or to use the mined chambers as an underground waste disposal facility without any requirement for backfilling. Often there is a combination of both.

This paper will give an overview of the available process technologies and show examples of planned and as-built stowing and filling installations in which the authors have been involved.

1. Introduction

In potassium and rock salt mining large cavities arise which for the most part remain unused during the mine's operational life. Once a mine has been closed the cavities which have been created are flooded as planned, although over the past few years there has been an evident tendency to use such cavities for commercial purposes.

Regardless of the reasons for backfilling underground cavities (waste depository, stowing etc.), it is absolutely necessary when selecting a process technology to take account of the following aspects:

⇒ spatial extension of the mine
⇒ existing infrastructure
⇒ special geological and geomechanical features
⇒ mechanical requirements for the stowing material used
⇒ physical and chemical properties of the substances to be stowed

The present paper does not deal with the selection and suitability of the materials to be stowed, but only the process technologies currently in use with due regard to technical considerations.

2. Process technologies

Basically there are four different process technologies for stowing materials in underground cavities:

⇒ open technique
transport in open vessels or trucks and stowing as loose bulk material
⇒ big-bag technique
transport and stowing in big bags
⇒ pneumatic technique
transport and stowing through piping by pneumatic conveyance
⇒ hydraulic method
Mixing of the material, transport and insertion through piping by hydraulic conveyance

Combinations of one or a number of techniques are possible and frequently in use here.

2.1 Open technique

The so-called open technique is technically the simplest and in practical terms it is equivalent to the age-old method in mining of product conveyance. The materials to be stowed are placed in open trucks or containers and transported underground on a frame using the hoisting equipment which is usually available. Depending on the infrastructure available, the simplest option is to transport the material in containers to a central dumping point in the field, where it is taken over by loaders and brought into the intended mine. If there is no (longer) an appropriate infrastructure additional intermediate transport may be necessary. In this case the material will then be transferred to heavy trucks in suitable mines near the shaft and the trucks will carry it to the dumping point. To ensure even dumping quality the material is normally compressed in layers as it is deposited. Any requisite roof connection can either be made with special equipment to push in the intermediate roof piece or by a combination with other techniques, such as pneumatic injection or slinging.

One special form of the open technique is the so-called in situ stowing, where the salt produced when mines are headed or salt extracted specifically for this purpose is inserted in mines to be filled.

The advantage of the open technique described here is its relatively simple machinery and process engineering, which puts its use in a favourable light in economic terms and reduces the necessary investments to a minimum. Pretreatment of the materials supplied is mostly not necessary. The maximum possible deposition capacity is determined not only by the distances to be travelled underground, but also by the capacity of the available hoisting facility.

It is a disadvantage that certain requirements have to be imposed on the material to be deposited with respect to moisture and its properties as a bulk material. For example, the materials may not be too dry (dust nuisance) or too moist (mud formation). Any additional process stage which may be necessary, e.g. to moisten or dry/blend with dry materials, requires additional process engineering equipment, which may then eliminate the economic advantage.

A further disadvantage is the fact that the range of the materials to be transported and deposited with this technique is restricted by the fact, that only materials with a low hazard potential can be handled because the possibility cannot be discounted that the operating personnel will come into contact with the materials.

Stowage using the open technique is employed, for example, at the Teutschenthal mine of GTS [1].

2.2. Big-Bag technique

With the big-bag technique the material to be stowed is put into big bags, which can be manufactured in different ways. Depending on the requirements, bulk materials are poured into big bags from silos or directly form ongoing processes. Another possibility is to condition the materials. Here certain material blends are created in a mixer to form a tough mass, adding liquid at the same time. Exploiting the thixotropic properties of this mixture, it is poured into big bags, where it is then solidified. To ease stowage underground and to achieve a bearing capacity, the big bags can be given a defined shape by means of formwork. Since a number of materials used in such a procedure have hardening properties, a not merely stable cuboid is obtained, which is suitable when clamped on three sides to absorb the compressive forces from the rock burden.

The big bags are normally transported with the help of stackers or roller conveyors to the shaft, where they are pushed onto the frame. They are taken off underground in a similar fashion. The big bags are loaded on trailers for horizontal transport and are driven to the stowing chambers. Stowage is adapted to the underground conditions. The big bags are either dumped or they can be stacked using special grabs in a controlled fashion in layers. Normally a complete layer is then covered with salt grit, which also fills the space between the bags. It is also possible to blow salt grit in to fill out the space up to the roof or to use a throwing belt to sling it into the space.

Stowage of unconditioned material in big bags does not for the most part require any major investment because the big bags are partly filled by the producer of the waste. If the waste is conditioned, a more elaborate installation is required for handling, blending and filling the bags. In any case, the capacity of such an installation is not particularly great because the containers are handled singly and have to be transferred a number of times.

Stowage of big bags in underground cavities is practised, for example, at the Kochendorf mine belonging to Südwestdeutsche Salzwerke [2].

2.3 Pneumatic technique

The pneumatic technique is preferred when the materials to be stowed have to be dry and of identical composition, i.e. when the underground cavities are to be filled, for example, with ESTA salt from preparation processes or residual salt from stockpiles.

With the pneumatic technique the materials to be stowed are conveyed by compressed air through a pipe and are blown into the cavity to be filled. A pneumatic conveying and stowing installation consists essentially of the following components:

- ⇒ bin or silo to take and provide intermediate storage for the material
- ⇒ blowing machine
- ⇒ conveying line
- ⇒ control and regulation device
- ⇒ compressed air generation and preparation

The material delivered to the mine is normally taken over as flowing bulk material in bins or silos. These facilities are equipped with appropriate discharge cones, and so they can be emptied in free flow without any further equipment. To regulate the quantity extracted it may only be necessary to equip the extraction facilities with, for example, rotary feeders. From the bins or silos, the material passes into the blowing machine. Where only one storage bin is available and the structural circumstances permit, the blowing machine can be mounted directly below the bin and then charged from it. Otherwise a suitable intermediate conveying facility is necessary, and this is normally a small feed belt.

The heart of a pneumatic stowing and filling installation is the blowing machine. In contrast to hydraulic conveyance, where the transport energy needed is fed to the finished mixture in the pump, with pneumatic conveyance first the transport energy is generated in the compressor and then the solid material is hurled from the atmosphere into the pressurised conveying line. This is the task of the blowing machine. In the practical case being considered here, practically only so-called rotary feeders are used.

A further major link in a pneumatic installation is the pipe system. The correct dimensioning is a prerequisite for safe operation and for guaranteeing the required conveying capacity. Since the conveying air is compressible, the compressed air relaxes as the conveying length increases and the air velocity rises continuously. In order to keep the velocity level within certain limits, the conveying line is graded upwards, i.e. the pipe diameter is enlarged in sections. A further point are vertical line sections on which longer, horizontal sections follow. As with hydraulic conveyance, a pressure increase can also be observed at the base of the shaft, although the reasons here are basically different. Whereas during hydraulic conveyance the pressure gain results from the weight of the material column, the reason in pneumatic conveyance is the compressibility of the air. The horizontal line section represents a resistance, on which the material falling downwards can also compress the air, as a piston does in an air pump. Although such a pressure gain can certainly be seen as positive, it must also be considered that a pressure increase leads to a reduction in volume and hence a reduction in velocity, with the risk of the pipe clogging. This effect must be considered in the design and planning of the conveying installation.

The compressed air needed is generally generated in compressors specially designed and dimensioned for the pneumatic conveying equipment.

The advantage of the pneumatic technique is the combination of conveying and stowing technology in one installation and the fact that the infrastructure of the mine is not burdened. Only one pipe needs to be laid from the surface to the underground cavity to be filled, and this pipe can also generally be accommodated under confined spatial conditions in the shaft or in small roadway cross section.

One disadvantage is the more elaborate machinery and the necessary compressor installation. In addition the moistness of the materials to be handled should be $< 2 - 3$ %.

The example of the Asse research mine belonging to GSF is a very good illustration of how the advantages of the pneumatic technique can be exploited to the full [3].

The Asse mine, a former potassium and rock salt mine, was acquired by the Federal Government in 1965 and transferred to the company Gesellschaft für Strahlenforschung (GSF) to enable them to conduct research work in the field of the final storage of nuclear waste.

During the mining of potassium and rock salt 1908 – 1964 a total of 131 chambers were created with a cavity volume of around 3.35 million m³, arranged largely on the south flank of the steep Asse saddle.

From 1967 to the end of 1978 a total of around 125 000 containers with weakly nuclear waste and around 1 300 casks with moderately nuclear waste were stored as part of the research.

Since the earlier chambers remained unfilled, the load-bearing elements in the form of ribs and pillars between the individual chambers were subjected to very great loads by the continuous rock convergence. In the course of the years there were therefore an increasing number of rib breakthroughs. The material breaking away at the roof and side walls increased and so finally the chambers could only be entered at great risk. For this reason about 850 000 m³ rock salt was stowed in the workings of the south flank from 1980 to 1989 to safeguard the mine in the long term. Because of increasing rock deformations over the past few years, continuation of backfilling on the south flank was an absolute necessity to improve the stability of this location. This was confirmed in particular by BGR as the appraisal body of the mining authority.

At the Asse mine positive experience had been gained from years of operation of a pneumatic conveying installation used for the vertical, upward transport of the rock salt mined from the deep workings into the chambers on the south flank. But since no-one could guarantee the required conveying capacity from the surface to underground, Deutsche Montan Technologie GmbH was instructed to conduct conveying tests to investigate the downward conveyance of mined salt and, on this basis, to design a conveying installation for the pneumatic transport of salt form the surface to underground. For this purpose both large-scale laboratory tests and in situ tests were conducted, the results are used in subsequent variation calculations. The definitive dimensioning was conducted with due regard to the effective pipe diameter available, as follows:

Conveying capacity:	130	t/h	salt
Air flow:	180		m³/min
Pressure:	3 bar		

Piping:

Surface:	150 m	175.0	mm
Shaft:	490 m	190.1	mm
Horizontal:	110 m	200.0	mm
Borehole:	210 m	199.1	mm
Horizontal:	400 m	231.9	mm
Total:	1360 m		

In accordance with this dimensioning the piping was constructed and the compressed air generation installation designed.

The stowing material chosen was residual salt from the stockpile of the former Ronnenberg potass mine near Hanover, which was selected from a shortlist of three salt materials drawn up after a Europe-wide invitation for tenders.

The stockpile salt is delivered in railway trucks and it is emptied into a silo installation. It is extracted from the silos using speed-controlled and individually selectable rotary feeders and discharged onto a conveyor belt, which in turn charges the blowing machine. This machine is of the type KSZ 250 S with a conveying capacity of 150 t/h max. salt.

The salt is conveyed pneumatically from the surface without interruption directly into the chambers to be filled and there it is blown out. Approx. 10 m before the pipe discharge a double-sided lye connection is installed to wet the stowing material with a view to binding the salt dust. In order to charge the chamber width of around 40 m and to ensure a good and complete filling of the cavities, a crawler truck with a telescopic boom extendable up to 35 m is used.

The compressed air supply is by means of a three-stage turbo compressor from INGERSOLL RAND, which supplies an air flow of 185 Nm³/min at 5.8 bar.

In addition to the installation control, the actual pneumatic conveying operation is monitored by measurement. For this purpose pressure measuring devices are installed at various points along the conveying line. The readings shown on the monitor can be used by the operator as the basis for controlling the conveying process.

By way of a summary it can be said that the process engineering selected of pneumatic conveyance and stowing has proven itself and the installation has been in operation since mid 1995 with a daily stowing capacity of approx. 1200 t salt. In all a total of approx. 1 000 000 t salt has been stowed to date.

2.4 Hydraulic technique

The hydraulic technique is one of the most efficient stowing methods for filling underground cavities. The filling materials are blended in an intensive mixing process with a liquid to form a homogenous, stable suspension. This is pumped from a pumping station on the surface using the hydrostatic pressure of the shaft piping directly from the surface to the chambers or cavities to be filled. This procedure differs from the classic flushing-stowing method in that no liquid has to be collected underground and repumped to the surface. Furthermore hydraulic conveyance proceeds with low velocities, in other words with laminar flow, which has a positive effect on the wear on pipes and fittings.

The properties of the stowing body underground can be largely varied by the selection of the stowing materials or the blending of different material groups. While in the case of a roof fall exlpoitation, the surplus water needed for conveying purposes is extracted from the suspension by the debris and so the stowing material remains in the goaf, by blending various ashes with, for example, pozzolan properties it is possible to create a hardening stowing mass. If strict requirements are imposed with respect to the load-bearing capacity of the stowage, the strength can be set to the desired levels by adding cement.

Since this method involves hydraulic transport over large distances and vertical sections, the properties of the suspension are of crucial importance for the operational reliability of the conveying installations. The specifications for making the suspension differ considerably:

⇒ The basic prerequisite initially is a stable suspension. A phase separation by sedimentation of particles very quickly leads to a clogging of the pipe. The sedimentation risk is very great when the conveyor is at a standstill. To avoid sedimentation it is advisable to keep the water content of the suspension as low as possible.

⇒ The suspension must also have favourable flow properties to enable it to be conveyed economically, i.e. with minimum pressure loss. Any increase in the water content makes the suspension thinner and thus lowers the pressure loss. This in turn cuts the energy costs for conveyance.

⇒ A further aspect is the question of the underground stowing technique. The accessibility and geometry of the cavities to be filled determine whether the stowing material has to be a thin suspension or a thick paste.

All these aspects initially require a close examination of the materials to be used in a suitable laboratory in order to establish a recipe which meets the contrary requirements indicated above. Since the stowing materials are often waste products whose conveying properties may certainly fluctuate, it is inevitable that the flow properties of the prepared suspension be checked continuously with an appropriate measuring procedure in the stowing installation. In the case of conveyance over long distances the anticipated pressure loss in the pipe is of crucial importance. A viscosimeter is needed for the measurements. As the stowing suspensions display a non-Newtonian flow behaviour and may also contain coarser particles, the standardised, commercially available viscosimeters can initially be discounted. In practice the tube viscosimeter has proven useful for this purpose [4]. Here a material sample is pumped through a pipe at different flow rates parallel to the mixing. The variables of flow rate and pressure loss measured over a specified pipe length can be converted according to certain laws into a pressure loss with a specified conveying quantity and a known pipe diameter.

It is important for the design of the piping that a laminar layered flow be ensured. If there are turbulences the solid particles in the medium can quickly destroy the pipe. With laminar flow the disadvantage is that solid deposits form on the walls of the piping and in the fittings. These grow over time and solidify. In extreme cases they can also clog the pipe. For these reasons the piping system must be cleaned, which is possible without difficulty using a largely automated pig at regular intervals.

In order to fill the cavities it is necessary to have an infrastructure which takes up little space and can be integrated underground. In general there is space in the shaft cross section for a pipe, which is the either suspended or set in the shaft wall. In the underground roadways the pipe can be laid wherever space is available. In busy roadway areas, for example, the pipe can be suspended in the roof and in less frequently used areas it can be laid on the roadway floor.

One conceivable solution is the filling of different cavities in campaigns by integrating pipe fittings with branching into different areas of the mine.

Inaccessible mine structures can be drilled in the roof without any further safeguards. An abandoned pipe is then installed in the borehole and the cavity is filled through it. Depending on the geometry of the mine structures and the flow properties set in the filling suspension, it is possible to fill the cavities through a small number of holes, sometimes even only one.

In the different branches of mining a number of installations are now in use with completely different functions. These range from filling abandoned salt mines with fine-grain ash in the form of thin suspensions and the filling of caved-in cavities in coal using pasty suspensions with different ashes and sludges, through to ore mines, where a hardening stowage is applied consisting of crushed mine waste and cement to produce and artificial roof.

Using the hydraulic technique it is possible to achieve high conveying capacity. For example, conveying rates of up to 100 m^3/h have been achieved with a conveying distance of up to 11 000 m. Double-piston pumps with a maximum pressure of 12 MPa are used here. To reach the workings without an intermediate pump, 8" pipes are used at a shaft depth of 850 m.

Since the hydraulic technique is a largely closed system, materials with a higher hazard potential can also be worked because there is no possibility of any contact between the stowing material and the operating personnel. It is thus also conceivable that this technique be used for dumping waste underground.

3. Summary

There are various conveying and process technologies available for filling underground cavities in mines. The technique used depends on the reason and purpose for the filling operation the technique most frequently used is probably pipe-bound hydraulic conveyance from the surface directly into the mine chambers. If dry material of the same kind as that already present is to be stowed, i.e. salt-based, pneumatic conveyance is a possibility. The fact that this can attain a high level of efficiency combined with operational reliability is illustrated by the case of the Asse mine. Where complete cavity filling is not required and an appropriate shaft infrastructure is present, the open or big-bag technique offers an inexpensive alternative.

All techniques have in common that the selection and planning must be in accordance with individual requirements and parameters in each case. Furthermore, with pipe-bound, hydraulic and pneumatic techniques in particular the operational planner must have considerable experience and extensive know-how to enable him to design and implement an efficient, operational reliable and economically efficient installation.

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