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A REVIEW OF WASTE DISPOSAL METHODS WITH EMPHASIS IN GEOLOGY AND TOXIC WASTE. PRESENT SITUATION AND PROSPECTS

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ABSTRACT

Production of toxic and other hazardous waste is inevitable, requiring the development of safe disposal methods (on surface or underground). In spite of various legislative and technical improvements the most important disposal methods remain the same (landfilling, underground cavern storage, deep well injection). All waste disposal methods need to take into account engineering geology and tectonic geology for site evaluation, in order to ensure maximum environmental protection.

ΠΕΡΙΛΗΨΗ

Η αναπόφευκτη παραγωγή τοξικών και άλλων επικίνδυνων αποβλήτων δημιουργεί την ανάγκη για ασφαλή επιφανειακή ή υπόγεια διάθεσή τους. Παρά την εξέλιξη της νομοθεσίας και των μεθόδων βιομηχανικής παραγωγής, οι κύριες μέθοδοι διάθεσης διεθνώς παραμένουν η υγειονομική ταφή, η διάθεση σε υπόγειους θαλάμους και η εισπίεση υγρών αποβλήτων σε βαθιές γεωτρήσεις. Όλες οι μέθοδοι πρέπει να λαμβάνουν υπ' όψη μια σειρά από παράγοντες με κυριότερους από αυτούς τις γεωτεχνικές συνθήκες και τα τεκτονικά χαρακτηριστικά των σχηματισμών που θα τα φιλοξενήσουν. Στην παρούσα εργασία εξετάζεται με ιδιαίτερη βαρύτητα ο ρόλος των δύο παραπάνω παραγόντων στη διαδικασία επιλογής και σχεδιασμού ενός χώρου διάθεσης.

INTRODUCTION

Huge quantities of waste are produced every year from human activities. Packaging is the most common household waste, while chemical and pharmaceutical industries together with metallurgy are responsible for most types of "difficult waste".

Taking into account the steadily increasing rate of waste production, the potential health problems and the environmental consequences, several countries introduced legislative requirements towards effective waste management which included production minimisation and recycling (glass, aluminium, paper). Nevertheless, there are technical as well as economical limits in the application of these waste management techniques. For example, varying quality is a major drawback for extensive industrial processing. Unwanted residue will be a problem for a long time to come and the only acceptable solution is landfilling.

The scope of this paper is to present the contribution of geotechnology and related subjects to safe toxic waste disposal in geologic formations. Future advances are also discussed in the same context. Geologic environment is used in three ways:

- Surface disposal of household and industrial waste.
- Disposal in underground caverns or existing mines.
- Toxic waste injection through deep wells into confined permeable strata, hydraulically separated from shallow, used, aquifers.

SURFACE DISPOSAL

General

Deposition of waste and inert material in natural topographic depressions has evolved to modern landfilling which is the most commonly used waste disposal method. Even though difficulty to locate a new site delays construction works, landfilling remains cost effective.

A modern landfill should be an impermeable box to surface, underground water and leachate. This is the definition of "full containment" and must be seen in contrast to "dilute and disperse" which was the philosophy applied not long ago and employed natural attenuation mechanisms. Leachate must be kept contained and treated properly until it is inert for public health since it can not be prevented from migration for ever.

The quality control programme must cope with health protection criteria and therefore the need for continuous monitoring is imperative (e.g. drinking water quality). Domestic waste, together with rainfall infiltrating in the site, will produce landfill gas (CO_2 & CH_4) and leachate until degradation, neutralisation and immobilisation mechanisms make it inert. From this point of view, a landfill is a "bio-reactor".

International landfill practice focuses on the following subjects:

- Proper geologic conditions (impermeable strata).
- Engineering works to secure low hydraulic conductivity.
- Collection and treatment of leachate and landfill gas.
- Site Monitoring.

Co-disposal of domestic, industrial, toxic waste and materials from mines in a sole site is beneficial when site selection is difficult and when waste composition is advantageous. To reduce development cost further, a different cell can be used for each waste type. Toxic wastes, mixed with other not harmful materials (organic compounds), may trap heavy metals and other insoluble substances and do not necessarily require special treatment. The main advantages of this method are therefore economic, since fewer sites are necessary for development, and environmental, since some toxic substances can be immobilised naturally.

A different concept for the selection of a landfill site is to vary selection criteria according to waste type. For example, three sites used for the disposal of inert materials, domestic and some industrial waste, and special waste respectively, should have different permeability and should have been engineered according to the safety features specified. Thus, special waste that requires minimum permeability would almost certainly utilise a combination of clay liner and geomembrane.

Environmental and geological criteria together with legal, political, social and climatic constraints lead landfill selection procedure to multidisciplinary analysis with a number of geologic and other special use maps organised more efficiently using Geographic Information Systems. Following the location of the final sites in situ and laboratory testing is necessary to establish soil and rock hydraulic and mechanical properties.

Construction and Operation of a landfill

To minimise leachate production preliminary stage calculations need to take into account all hydrologic parameters. The equation describing leachate retained at the site [1, 9] is:

$$L=P-E-A\cdot W+R_1-R_2$$

where:

L: Leachate

P: Precipitation on site

E: Evapotranspiration

A: Waste absorption capacity

W: Weight of waste

R_1: Run on (surface and underground water)

R_2: Run off (ditto)

A number of active and passive engineering techniques are available to the engineer. Active systems comprise draining wells for draining and pumping out leachate and gas. Passive systems, on the other hand, comprise natural or man made impermeable barriers that cut off leachate migration. The most commonly used techniques are:

- Compacted clay barriers with appropriate geotechnical properties (Atteberg limits, compressibility, strength) at least 1 m thick.
- Geomembranes (HDPE, LDPE). Use of geomembranes must be coupled with protective gravel at least 30 cm thick and drains to keep steady hydraulic head.
- Bentonite (3-6% pw) mixed with sand (fine particles 20-30%) [6] or bentonite (15% pw) and sand to achieve permeability 2.3×10^{-10} m/sec [4].
- Combination of the former techniques.

It is important to note that not only the bottom but also the sides of a landfill need to be impermeable and that one should place waste in a way to prevent differential settlement.

At the end of a landfill site operational life an impermeable soil cover, permanent or temporary is appropriate to:

- minimise infiltration,
- maximise run off,
- reduce landfill gas emissions into the atmosphere and facilitate gas collection

- border waste and not permit to roots or animals to contact waste.

Leachate collection and treatment systems are necessary if waste is rich in organic content. At least a few piezometers are appropriate for monitoring purposes but more advanced techniques, with respect to special local conditions and the objectives set, are also operational. Chemical analyses of surface and ground water near the site, or just below the liner, allow for immediate remedial measures in case of liner failure whereas, monitoring wells located far from the site do not provide an early warning system.

Future Advances

The landfill type described above is adequate for the time being but, given the dramatically increasing environmental sensitivity, there is a need to pass on to a waste storage centre which will operate under strict and specific laws. A number of new technologies and survey methods are necessary for this change. With regard to landfill selection a simple survey of local geology is not sufficient. One need to consider a great number of parameters and criteria which are often antithetical. Tools like G.I.S. become even more useful under these circumstances especially where quantitative assessment and weighting are adopted [7]. However, use of such computer systems can not substitute raw data coming from field measurements.

Natural or man made materials must conform to more and more demanding specifications regardless of their use in new storage centres or old landfills. Quality control should go beyond material production and the first stages of a construction work and investigate material behaviour under adverse conditions (leachate, weather) with time.

Detailed computer models for pollutant migration are useful but to get reliable results we need to understand better the operational mechanisms and the input data. To confirm predictions careful sampling and testing are absolutely necessary.

The subject of waste disposal is evolving towards new disciplines. Now that everybody understands no barrier is completely safe for ever, we should consider mechanical or chemical processing to reduce toxicity. From this point of view waste is only the "final residue" without any probable reuse.

UNDERGROUND STORAGE

General

Underground storage is a satisfactory solution for soluble toxic waste if there are restrictions for surface disposal. The cost of underground storage in caverns excavated for that purpose or in existing mines remains higher than for ordinary landfills. Therefore it is cost effective only for small quantities of difficult waste requiring special treatment. Disposal into thick geologic formations ensures that waste will stay out from human environment for many years.

Long term security however depends on waste toxicity. To achieve low risk a lot of protective measures are necessary:

- Careful site selection at areas without any tectonic activity, simple and easy to understand geology, and as little as possible underground water.
- Use of multibarriers (e.g. storage in barrels and use of geomembranes).

- Study possible toxic waste leakage scenarios.

Favourable geologic conditions are [5]:

- No seismic activity.
- Thickness of host rock less than 400 m.
- Permeability < 10^{-8} m/sec and unconfined compressive strength >50 Mpa.
- Very good surface run off and minimum seepage.

In Greece evaporites (mainly gypsum) could be utilised for underground storage provided that seismic activity is minimum (Fig. 1).

Use of tunnel boring machines to excavate the waste storage site has been suggested [3] in case of no alternative sites available (e.g. old mines). The same authors suggest excavation in massive rock in a number of revolutions (spins) to reduce dismantling. This way cost is going down making underground excavation more attractive against a classic surface excavation.

Future Advances

If reclamation of a surface disposal site is difficult then reclamation of an underground waste storage site is impossible. Rock mechanics, hydrogeology and geochemistry need to work together to improve site survey techniques aiming at a long term safety design. Site monitoring during the operation stage and the post closure stage should employ more sophisticated equipment that is not yet available.

Figure 1. Evaporites at Kastro - West Pelloponese. Even though similar rock types can be considered for underground storage of toxic and radioactive waste, this area is totally unacceptable due to diapirism and earthquakes which result in unwanted movement.

DEEP WELL INJECTION

General

Deep well injection of toxic waste into permeable geologic formations is based on know how acquired by the oil industry. During the 70's 60% of USA toxic waste was disposed this way [1].

More and more demanding legislation resulted in the abandonment of the deep well injection technique and, at the same time, reduced the risk of pollution. The key feature is presence of a permeable formation confined between impermeable strata acting as a barrier to the migration of toxic waste. Good injection media are sandstone, limestone and dolomite. The injection zones should have the following hydrogeologic and geologic characteristics [2]:

- Absence of underground drinkable water.
- Not used for hydrocarbon or geothermal fluid repository.
- Chemical composition not allowing any reaction between host rock and waste.
- Permeability of at least 10^{-6} m/sec.
- Predictable pore pressures and flow (known hydraulic gradient to assess underground water flow).

In addition the host rock should lie within low seismicity and volcanic activity regions without faults or other discontinuities. However, deep well injection was used satisfactory in Milos Island (Fig. 2).

The Environmental Protection Agency (EPA) suggested more quantitative criteria [8]. According to these, deep well injection is effective if:

- injected fluids do not migrate out from the host rock for 10,000 years,
- injected fluids do not mix with drinkable water (TDS < 10 mg/l) &
- waste is inert when it moves towards an aquifer.

Future Advances

Future developments in this field have to deal with precision of long term behaviour. Hydrogeology, based on oil mining and natural gas industries should work towards this direction.

More specifically, better understanding of the following subjects would be more than welcome:

- Classification and description with regard to the geometry and permeability of injection zones.
- Monitoring techniques.
- Interaction between host rock and waste.
- Well equipment.

CONCLUSIONS

Landfilling under the principles of “concentration and confining” [1] is the prevailing waste-disposal method. Landfill site selection is an exercise to balance legislative, political, social, climatological, geological, geotechnical and environmental criteria. The use of Geographical Information Systems is appropriate to evaluate each parameter and design accordingly. Monitoring systems are also necessary to form the data base and provide the means for quality control. The final construction usually includes both passive and active containment systems.

Figure 2. Toxic geothermal fluids in an open tank at Zefiria -Milos Island. The reservoir is water tight to avoid land contamination. Due to the limited volume available, fluids were inserted into deep geologic strata through an adjacent fault zone.

Underground cavern storage is much more expensive than landfiling which automatically makes it less popular. From a geological point of view, rock mechanics, hydrogeology and geochemistry working together, will improve our knowledge and allow safe, long-term, operational life.

Deep well injection normally uses sandstone, limestone or dolomite which are abundant in Greece. Injection zones must fulfil hydrogeological, geotechnical and geological criteria to ensure environmental protection. Future improvements on waste disposal should look into monitoring techniques and the understanding of waste - rock interaction.

Increase of waste production and environmental protection requirements now bring geology and waste management closer together. Geosciences in general play a key role in the following subjects:

- Site selection and classification.
- Environmental impact assessment.

- Monitoring during operation and post closure stages.
- Construction (e.g. liners and quality control).
- Land reclamation.

Engineering geology and environmental geotechnology in particular, can give a straight forward environmental assessment (soil, bedrock, underground water) for any site and for each waste disposal method. To achieve this the following works should be carried out, as part of a competent survey, in association with other specialists.

- Geologic mapping and G.I.S.
- Field and lab testing.
- Material quality.
- Digital flow models.
- Site monitoring.

Cumulative experience from the use of new exploration monitoring and construction tools will project the role of geosciences and result in more effective waste management.

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