Cavity Utilization in the Netherlands

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ABSTRACT

The Dutch salt domes in the northeastern part of the country were, owing to their isolated position, of no importance to the storage of products. The industrial centres of The Netherlands, situated around the cities of Rotterdam and Amsterdam, are connected with the natural gas fields of Slochteren and the North Sea by a complete system of high pressure, large diameter pipelines and compressor stations. At the same time the Dutch, and even part of the Belgian and German, strategic oil reserves are stored in huge surface tank areas around Rotterdam.

That is the reason that Akzo's salt chemicals division already started investigations for other uses of their cavities in the sixties. As a result of these studies AZC started the disposal of slurries from its brine purification plants in Hengelo, followed a few years later by small amounts of salty drilling muds. In the seventies plans were worked out for the disposal of chemical wastes in small caverns, specially made for this purpose, one above the other as a string of pearls from one drilling. A successful solution mining test resulted only because of the negative attitude of the Dutch environmental authorities. At this moment a huge cavity is used for the storage of concentrated $MgCl_2$ brines. Together with the international oil industry working in The Netherlands, plans have been developed and permits applied for in view of the disposal of the complete range of drilling muds and cuttings produced in our country. A new item for underground disposal in salt cavities could be the waste products of coal-fired power plants.

INTRODUCTION

The Royal Dutch Salt Industry started the production of salt in The Netherlands in 1918. For several obvious reasons solution mining was chosen as the mining method. The underground cavities resulting from this method were not considered useful at that time.

During the sixties important developments were achieved in regard to the possibility of controlling the shape of the cavities that were developed. In particular, the use of blankets, gas or fluid, and the development of the echo-sounding technique were of extreme importance. From that time on cavities were considered as possible storage facilities for various products or wastes. Anticipating these developments as early as 1938, our company started the disposal of wastes from our brine purification units into existing cavities in the Hengelo area. This was followed by the disposal of our own used salty drilling muds around 1965.

Although the Dutch Salt Industry was accustomed to the idea of underground disposal of waste products, activities in this direction were delayed by the unfavourable geographical situation of the salt formations in The Netherlands with regard to the industrial centres of the country, where heavy industry is mostly situated along the western seaboard. In the areas of Rotterdam and Amsterdam, in particular, an accumulation of highly energy-consumptive industries is found. However, the discovery of the Slochteren gasfield in the utmost northeastern part of Holland has entirely changed the picture of the primary energy fuel used (Figure 1). Coal-fired power plants were shut down, while oil-fired ones were reconstructed for the use of natural gas. The complete distribution network for coal gas was dismantled and a new pipeline system was installed for the use of natural gas, not only for industrial, but also for domestic purposes. At this moment 81% of Dutch electricity production is based on natural gas as the energy source, and for central heating and cooking at home this figure will be even higher.

Differences in the summer and winter consumption of natural gas could easily be met by the extremely favourable properties of the Slochteren gasfield, at that time the third largest field in the world. Daily peaks were obviated by an extensive high-pressure, large-diameter pipeline network throughout the larger part of The Netherlands.

Although the existence of several excellent salt domes in the same area as the Slochteren gasfield was known, the use of these domes for gas storage was never seriously

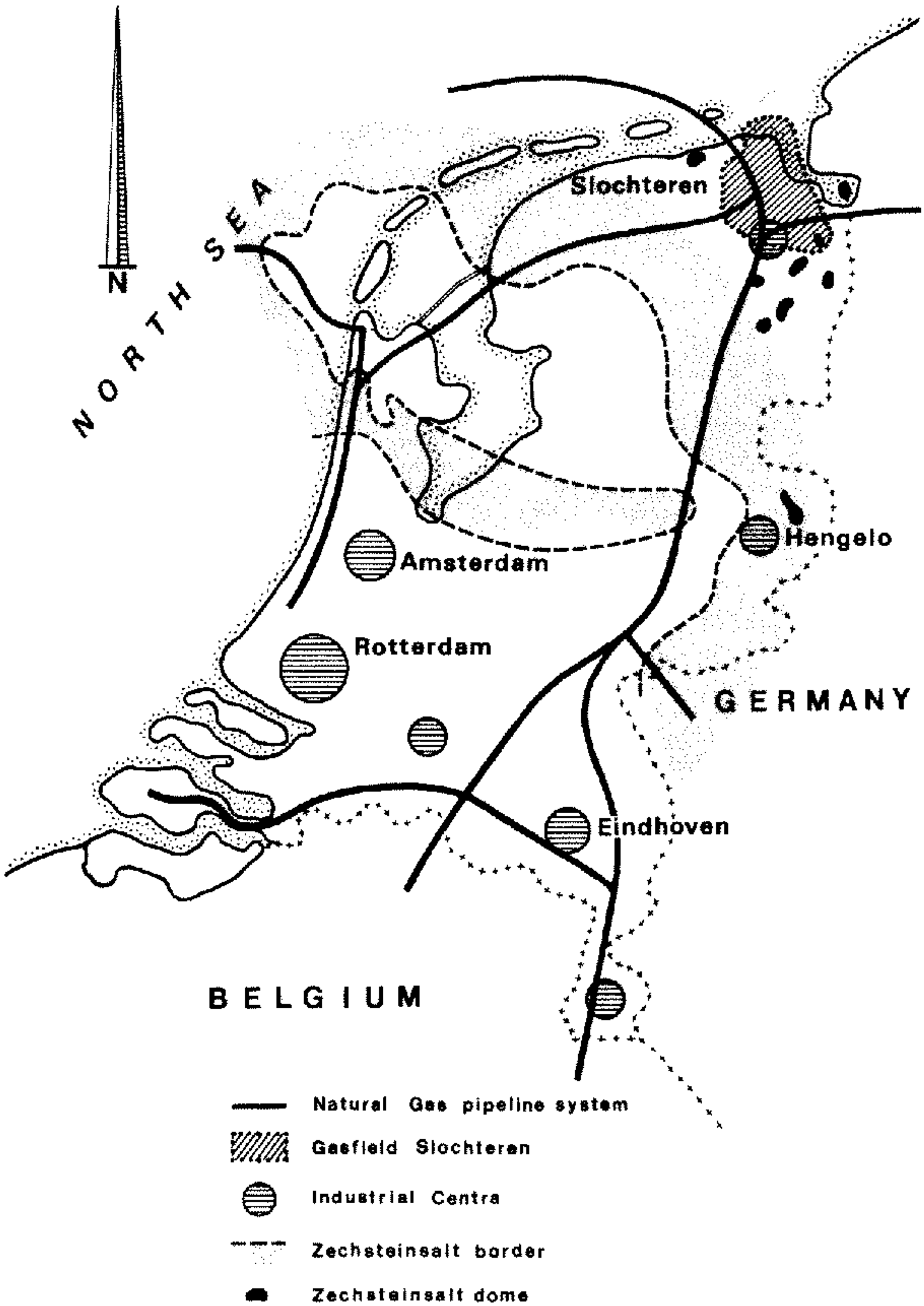

Figure 1. Infrastructure of The Netherlands.

considered before 1980. There was no need either for new storage capacity for crude or oil products to meet the demands of the EEC for the storage of a ninety-day consumption reserve, because the storage capacity of the surface tank parks in the Rotterdam area is even large enough for part of the Belgian and German strategic oil storage. In the near future only summer storage and mixing facilities for different qualities of natural gas could perhaps be considered from an economic viewpoint in case of further developments of the North Sea gasfields and imports of foreign gas.

As a result of this situation we are forced to look for other possibilities of secondary use of our salt cavities.

WASTE DISPOSAL CASES

The Dutch Salt Industry has concentrated its salt production in two areas. The oldest site lies in the eastern part of our country near the German border, where salt production was started in 1918 from a Triassic salt stratum of about 50 metres average thickness at a depth of 400 metres below ground level. The production plant was constructed on top of this salt formation. In 1954 production came on stream also in the northeastern region of The Netherlands, based on two Zechstein salt domes. This plant was erected in the harbour area of Delfzijl, at some 20 kilometres distance from the drilling site (Figure 2).

In Hengelo the water system for the brine production can be maintained in a closed circuit, since the production plant has been built on top of the brinefield. As a matter of course investigations were started to find out whether the wastes of the raw brine purification plant could also be disposed of in the same circuit into the salt cavities of this nearby brinefield (Figure 3).

Nowadays, these waste products are a mixture of calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), gypsum ($CaSO_4 \cdot 2H_2O$) and magnesium hydroxide ($Mg(OH)_2$). This mixture is slurrified, with waste waters and waste brines from the production plant, in a storage tank equipped with a mixing gear. At slight overpressure this slurry is pumped with centrifugal pumps through a glass-fiber-reinforced pipeline of 6-inch diameter into the cavity of an abandoned production well. The quality of the displaced brine is controlled and determines the disposal capacity of the cavity. For example, we started filling Well 15 in 1961. This well had a diameter of approximately 100 metres and roof cave-in caused us some problems. When it was still possible to do so, it was decided to fill up this cavity as far as possible in order to prevent damage from subsidence at the surface (Figure 4). A solid:liquid ratio of 30 volume per cent solids was chosen in order to avoid easy settlement of calcium carbonate particles in the pipeline. The average volume pumped per day has increased from approximately 180 m^3/day (47,550 Am. gallon/day) to 320 m^3/day (84,550 gallon/day) during the following nine years. A total volume of 212,000 m^3 (7,500,000 cubic feet) of solids was disposed of into the cavity of an original volume of 191,000 m^3 (6,750,000 cubic feet). The enlargement of this cavity to a volume of about 248,000 m^3 (8,760,000 cubic feet) was the result of the dissolving action of the unsaturated slurry. Fifteen per cent of the cavity volume was still filled with brine when the well was closed, and an additional 190,000 long tons on top of the 414,000 tons of salt was mined by the displacement of the original brine and the enlargement of the cavity (Figure 5).

In the meantime, the production method in Hengelo had changed from a single into a double or even triple well system. After closing Well 15 our disposal activities were directed toward the elongated cavities of a double well. Several of these old hydraulic fracturing wells also were selected for disposal and shut down in an earlier than normal stage of production. This was done to avoid an irresponsible enlargement of the cavity by the unsaturated waste brine during the disposal phase and the problems encountered in keeping the blanket in place during the production stage.

In these elongated cavities the angle of discharge of this waste into a fluid medium is very important to the ultimate filling capacity. In the laboratory tests an angle of 20 degrees was measured, and this measurement was confirmed in practice by the echo-soundings in several disposal wells. The filling rate can be reckoned to be 70% for the elongated cavities with their relatively unfavourable height-to-diameter ratio. For example, in Well 102-103 about 45,000 m^3 (1,600,000 cubic feet) of solids were already stored at the moment of the echo-sounding (Figure 6). It is expected that in total more than 80,000 m^3 (2,800,000 cubic feet) can be disposed of, exclusive of the additional space by the cavity enlargement caused by the dissolving action of the unsaturated waste brine. These wells will be taken into production again after filling their cavities with up to 70% solids from the brine purification plant. This procedure can be followed only if the waste brine is of a similar type and quality as the production brine. There should not be any pollution of the displaced brine by the disposed waste.

In this particular case there still is plenty of rock salt left at the roof, because the production shut-down has taken place rather early in the lifetime of these wells.

MAGNESIUM CHLORIDE STORAGE

In 1977 Akzo and Billiton started discussions about the storage of magnesium chloride by means of displacement in a salt production cavity. Apart from the relatively low investment costs for huge quantities, other advantages can be mentioned. For example, the displaced brine can be mixed with the brines from other salt production wells

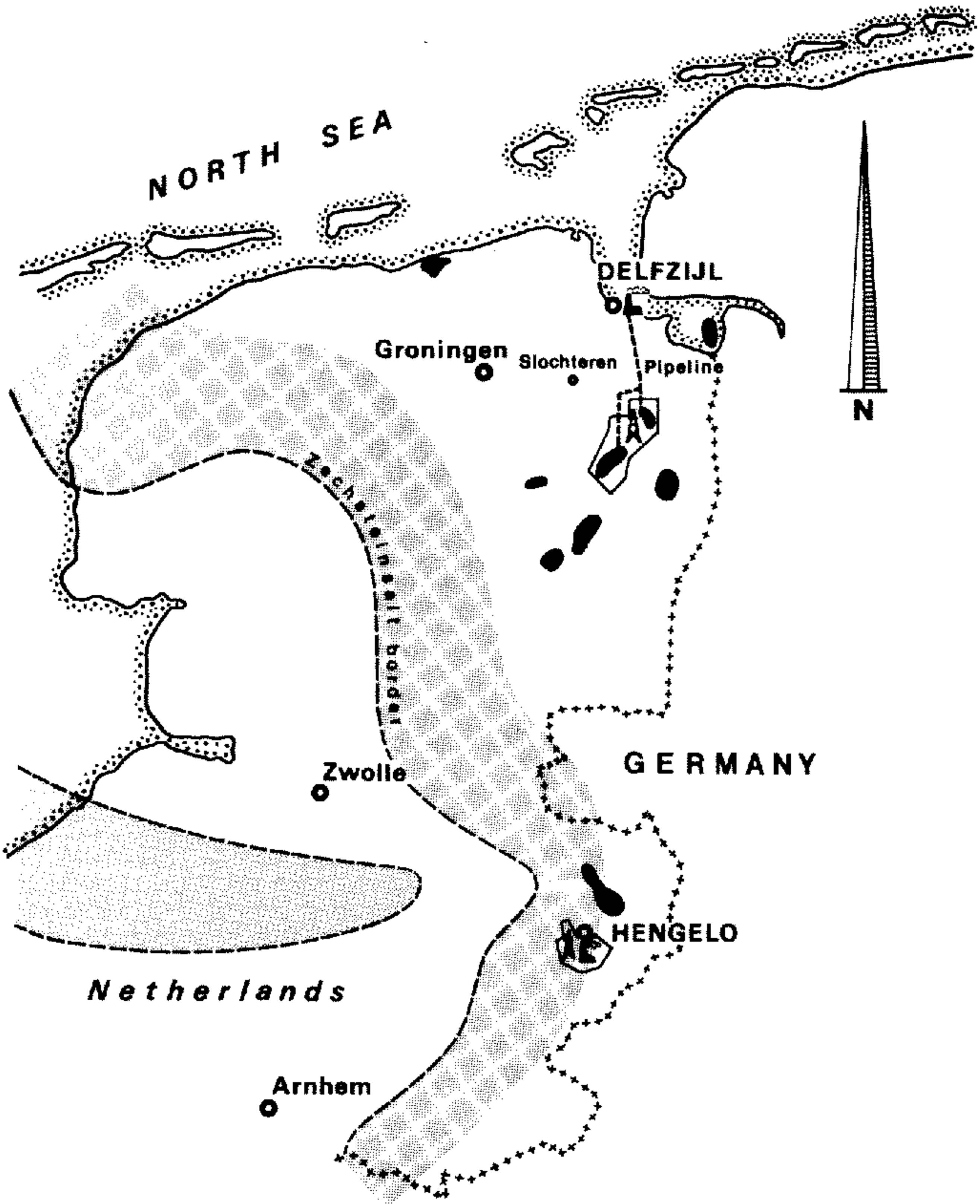

Figure 2. Location of the salt production plants of Akzo in The Netherlands.

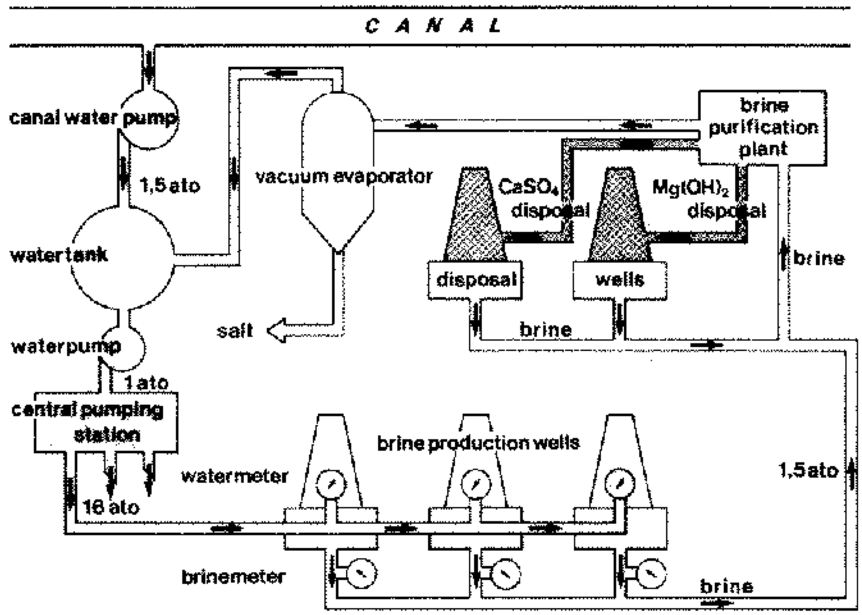

Figure 3. Brine production and waste disposal system of the Akzo's Hengelo site.

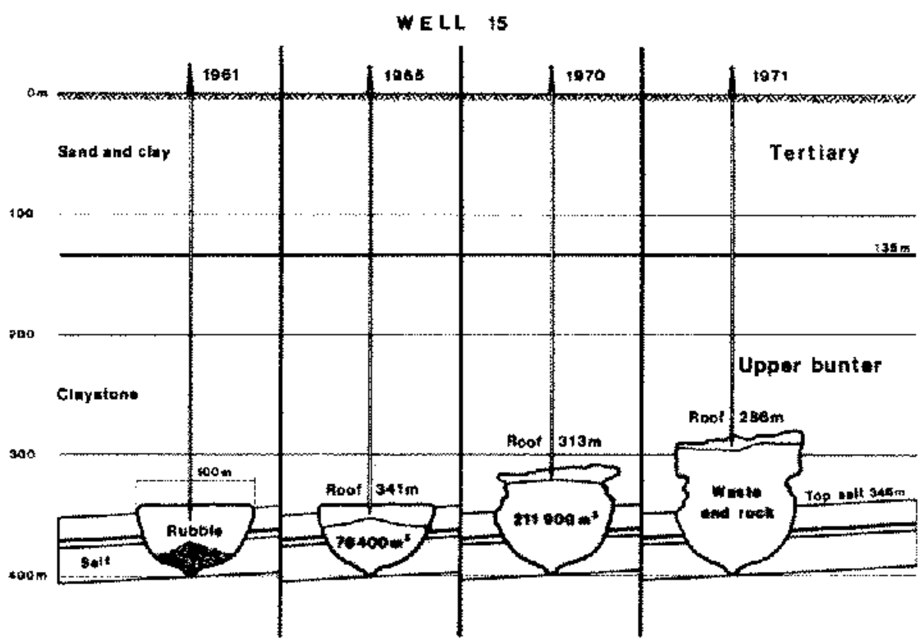

Figure 4. Filling history of the waste disposal Well 15, Hengelo.

and used for normal salt production, while for the displacement of the magnesium brine during the emptying stage saturated brine will be available from the same wells (Figure 7).

The main concern of this system was the inadvertent mixing of these two brines, because an increasing concentration of magnesium in the sodium chloride brine would be undesirable in the brine purification unit of the salt plant. Several investigations into this subject were performed by the Shell Laboratories of Amsterdam.

A rather sharp interface between the two brines could be achieved if the heavier magnesium chloride brine is injected under laminar conditions at the bottom of the cavity. A mass transfer will then occur in both directions across the interface. In this case the mixing process can be described by pure diffusion and mass transfer by a

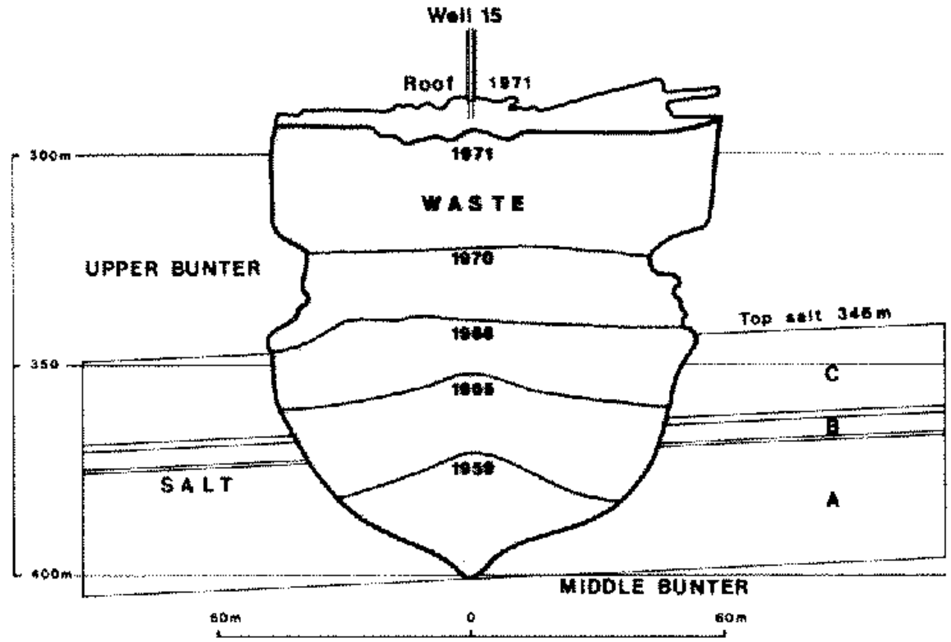

Figure 5. Summary of the filling rate of the waste disposal Well 15, Hengelo.

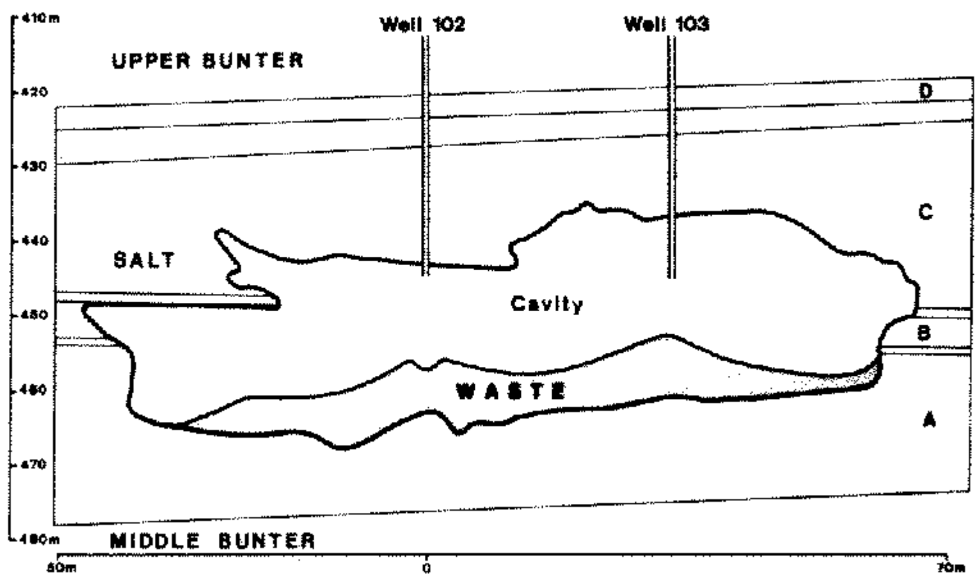

Figure 6. Waste disposal in a Hydraulic-Fracturing connected well system in the Hengelo area.

thermo-convective flow along the walls of the cavity and the interface of the two brines. However, it was felt that the diffusion transport would be of minor importance in comparison with the influence of the thermo-convective flow on the total mass transfer. This convective flow is due to the temperature difference between the formation and the brine in the cavity. This temperature difference increases from the top toward the bottom of this cavity with a total height of 600 metres and is caused by the production of brine with injection water of about 10° Celcius (50°F).

The heat flux to the cavity must be very small and could be measured by the slow temperature rise of the brine after a certain time of production stop. Under these circumstances and the relatively high density difference of 60 kg/m^3 (0.5 lbs/gallon) between the two brines it is

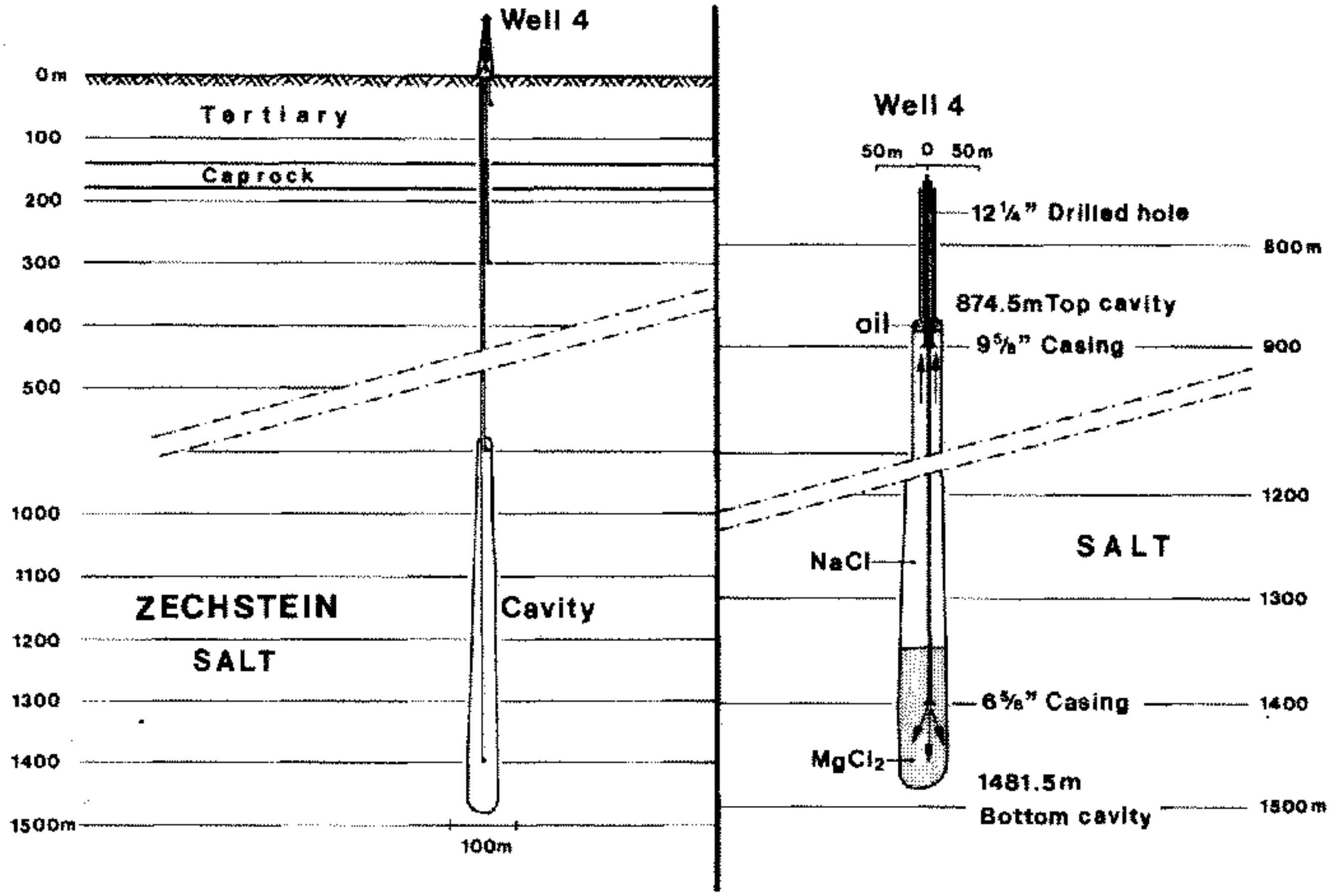

Figure 7. Storage of $MgCl_2$ brine in Well Zuidwending 4, Salt Dome Veendam.

believed that the interface is very stable and that the magnesium concentration in the bulk brine will only rise about 10 ppm during a storage period of one year.

The magnesium brine contains 18 per cent magnesium chloride by weight, 6 per cent potassium chloride and only 2 per cent sodium chloride. The potassium content makes it possible to measure the interface of the two brines very accurately by means of a gamma-log. In this well the deflection of the gamma-log amounts to 2 API-units for normal brine. This is in sharp contrast to a deflection of 30 API-units for the magnesium brine (Figure 8). The rather sharp and over-the-time constant deflection change at the interface proves a poor mixing of the brines. The magnesium brine was delivered by trucks during the experimental stage. In total 100,000 m^3 (3,530,000 cubic feet) has been stored in a period of about 3 years. Much care has been taken toward a laminar flow at the filling point at the bottom of the cavity. For this reason a small tank unit was built at the surface to ensure an equable filling rate of the cavity. Also a specially designed casing shoe was installed to get a stable undisturbed interface. This installation is remote controlled and provided with several safety measurements.

At the moment, a reversed procedure is followed and the magnesium chloride brine is pressed out of the cavity by NaCl brine for further use.

FUTURE POSSIBILITIES OF WASTE DISPOSAL

Together with the international oil industry in The Netherlands, plans have been developed and permits applied for in view of the disposal of the complete range of used drilling muds and cuttings. The increased exploration and exploitation activities for oil and natural gas in our country are responsible for the production of about 225,000 m^3 (7,950,000 cubic feet) of used drilling muds and waste waters and of 75,000 metric tons (83,000 short tons) of cuttings per year. A substantial part of these wastes are loaded with salt, and dumping of these salty muds on surface dump areas or surface waters is, of course, considered harmful to the environment, especially in a country with a high population density. For this reason the larger amount of the drilling mud is still dumped into coastal waters. Existing cavities are situated so near to the most important gas and oil fields in Holland that they could provide an inexpensive disposal al-

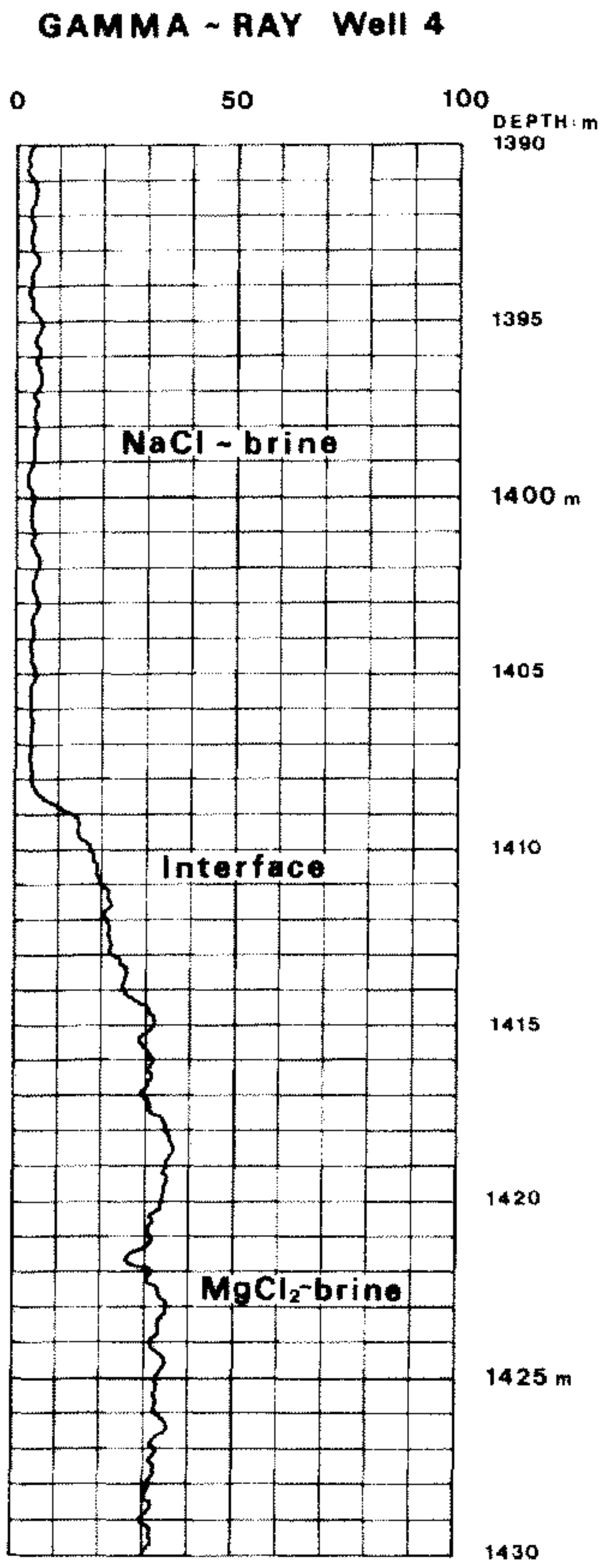

Figure 8. Magnesium chloride storage Well Zuidwending 4.

ternative. Akzo has developed an installation for the dumping and working-up of mud and cuttings (Figure 9). In this installation the cuttings are slurried up with the mud and then, only if necessary with brine or water, pumped directly into the waste disposal cavity. This installation can also be used for other bulk waste products such as fly ash from coal-fired power plants.

If the method is based on the assumption of a re-use of the displaced brine for the production of salt, the choice between the method of displacement, or of previously emptying the cavity by pumping out the brine by a deep-well pump, depends on the chemical reactions between the waste product and the sodium chloride brine.

The experiences gained with the storage of the magnesium brine have taught us that displacement can be used in several cases and that if the displaced brine can be used partly for conditioning of the waste slurry, chances are even better.

In the case of the displacement method, every controlled salt production cavity can normally be used. But the question whether the cavity after filling up with a slurry can be closed and abandoned should still be answered. The geological situation and the shape and size of the cavity are most important features in solving this problem. Akzo has tried to answer this question in cooperation with The Bundesanstalt für Geowissenschaften und Rohstoffe, Hanover (Langer, Wallner, 1983).

For the geometric ratio and depth of a normal cavity in the Veendam salt dome, several calculations have been made on the influence at the roof area of an equilibrium between the inside fluid pressure and the primary rock pressure at the bottom of the cavity. In this special case the calculations are based upon a fluid-filled cavity of some 500 metres height. The maximum inside pressure at the roof will be on the order of 24.1 MPa at 920 metres depth after a period of time, in comparison with a rock pressure of 20 MPa at the same depth. The increase of the inside fluid pressure due to convergence of the cavity walls is, even with a conservative estimate of the creep rate, still a very slow process in the case of the Veendam salt dome. It has been demonstrated by detailed numeric calculations that tensile stresses will not occur around the roof area and fracturing of the salt is not to be expected.

The same calculations are made for the case of an empty cavity. Special measures are to be taken for reasons of stability and convergence. At present, several tests are under way to determine the technical requirements and the capacity of a specially constructed deep-well pump and its dependence on the depth of the cavity.

CHEMICAL WASTES

The disposal of chemical wastes could be a further possibility for the use of cavities in salt. However, the displacement method normally cannot be used because of

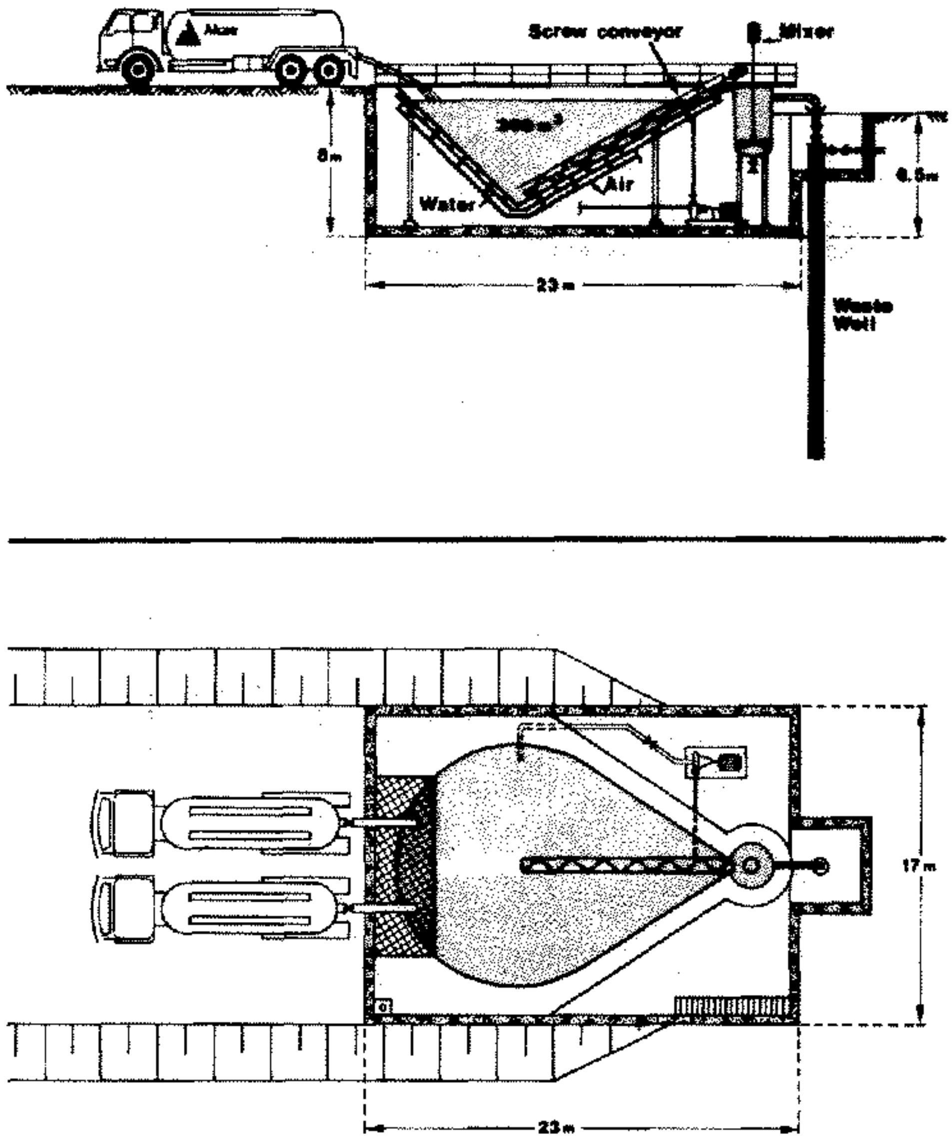

Figure 9. Installation for working-up and dumping of slurries in an underground cavity.

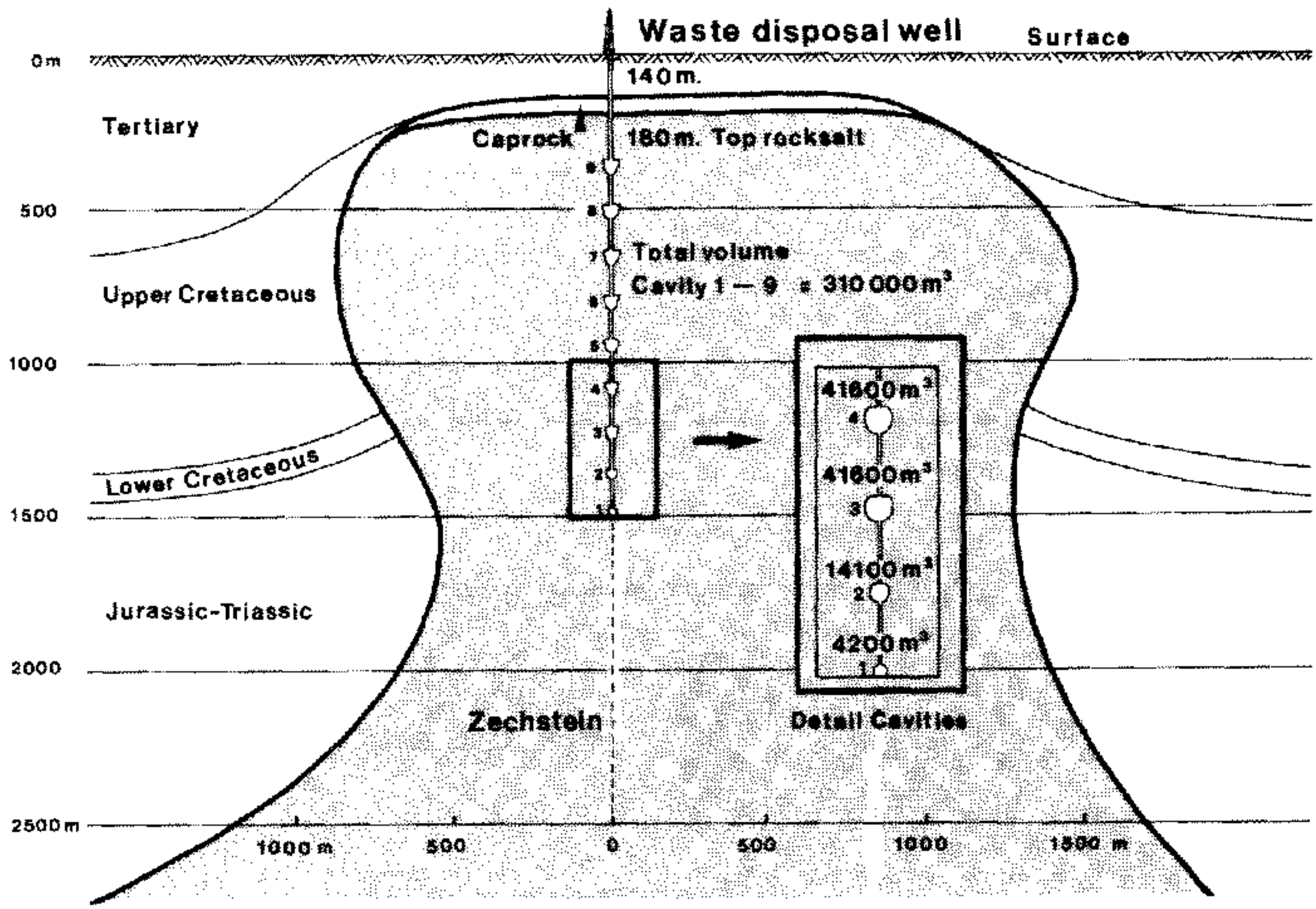

Figure 10. Suggestions for chemical waste disposal in a salt dome.

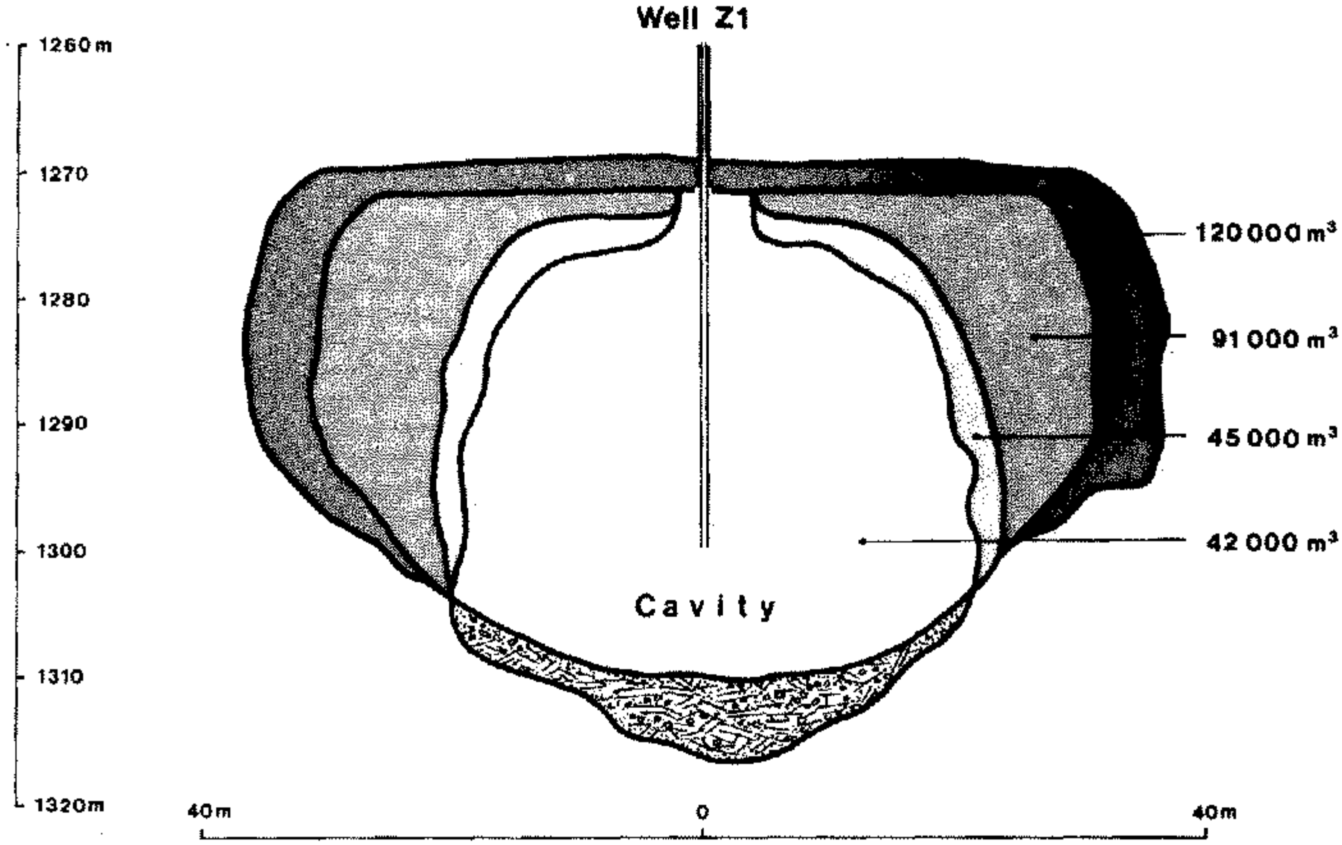

Figure 11. Experimental cavity for chemical waste disposal.

the chance of pollution of the brine by these wastes. Moreover, in case of interactions between different chemical wastes and brine, a smaller size cavity has to be chosen for reasons of operating flexibility. In that case multiple small cavities are preferred because they each can be used for the disposal of a different waste product. But, of course, a small cavity will in normal circumstances be relatively more expensive from the point of drilling costs. For that reason Akzo worked out the idea of a "string of pearls," being a number of small cavities mined out, one above the other, out of one well (Figure 10). If a cavity is mined out, it has to be emptied by a deep-well pump. Having been filled up with waste, it has, in turn, to be closed again with an open hole packer, for example, a Halliburton EZ-SV packer and a cement plug. A new cavity thereupon can be mined some 100 metres higher up. In that case one group of waste products will require at least two wells, one for the disposal phase and the other for mining a new cavity. Akzo did some experimental work in creating a small cavity at a depth of about 1300 metres. We succeeded in making a spherical cavity with a diameter of 42 metres (140 feet) and a volume of about 42,000 m^3 (1,480,000 cubic feet). This cavity has an ideal shape for emptying and disposing of chemical waste (Figure 11).