Reducing environmental impact of in-pit ash disposal

La réduction de l'effet de l'environnement sur le traitement de cendres dans les puits des mines

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SYNOPSIS A description is given of an investigation into the stowing of power station ash in the mined-out portions of an open-pit coal mine so as to limit environmental impact. It was decided to place the ash above the restored phreatic surface in the pit thus reducing the transfer of soluble salts to a river bordering the site and to an underlying dolomite aquifer.

INTRODUCTION

A new thermal electricity generating station of 3600 Mega-Watt capacity will be fuelled by coal from an adjacent open pit mine. About 230 million tons of ash are expected to be produced during the forty year life of the station. The disposal of this ash with a loose volume of close to 250 million cubic metres, is obviously a problem with major environmental implications.

Investigations were made for disposal of ash in the following ways :

1. In the pit, with ash positioned at the bottom of the excavation, below the restored water table.
2. In the pit, with the ash positioned at the top of the replaced overburden, above the restored water table, with a relatively thin soil cover.
3. On a surface in an area underlain by andesite lava which was likely to be free of major aquifers.

For the third case above, investigations considered both dry disposal using stackers, supplemented by mobile earth moving equipment and disposal of the ash in slurry form.

The writers, after completing their investigations, recommended the adoption of surface disposal because this method would cause a minimum of underground and surface water pollution and also because they considered it the most cost-effective method of ash disposal at this site.

The owners of the facility, the Electricity Supply Commission, decided, however, to adopt the in-pit dry disposal system with the ash placed in a 20m thick layer located near the surface of the backfilled pit. This location would minimize groundwater pollution from in-pit disposal.

REASONS FOR PREFERRING IN-PIT DISPOSAL

Figure 1 shows the location of the power station, the open-pit mine and the site for surface disposal of the ash. The mine will be located on the inside of a loop in the Vaal River, giving a river frontage of 18km. The site for surface disposal is across the river and some 7km from the Lethabo power station. Directly across the river from the mine is the large industrial and residential town of Vereeniging.

As the Vaal River is the major source of water for the Pretoria-Witwatersrand-Vereeniging complex, a residential and industrial area of some 10 million inhabitants, the possibility of soluble salt transfer from the ash to the river was clearly a most important consideration. Because of the leachable constituents of the ash, there is a threat of salt transfer however the ash is stowed. Surface disposal simplifies salt control, but increases the problems of wind-borne dust and of visual intrusion. Moreover a large area of farmland would be sterilized by the formation of a surface dump. There is also the problem of transporting the ash cross river and overland by pipe-line or conveyor with the accompanying visual intrusion and dangers of spillage along the route.

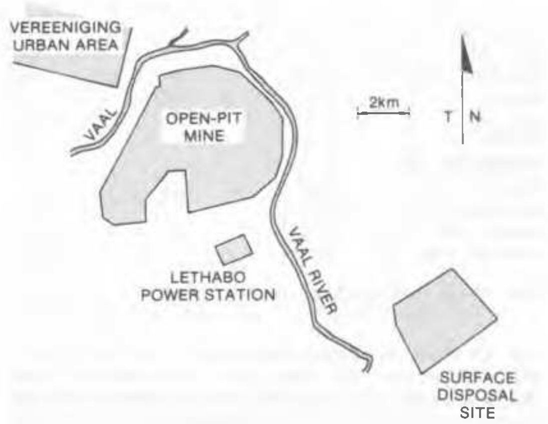

FIGURE 1

Location of possible ash disposal sites.

Perhaps the clinching argument for in-pit disposal arose from the fact that if the ash is not returned to the pit more of the surface level of the 2700 ha mined-out area will be below river level. It would be difficult to prevent the formation of a swampy wasteland unless the backfill were properly contoured. If the ash is returned to the pit, however, surface contours can be restored to something approaching the pre-mining topography.

LEACHABLE CONSTITUENTS OF ASH

The leachable constituents likely to occur in the ash were assessed by means of a test programme on ash taken from a number of nearby pulverised coal-fired power stations. Water was percolated through specimens of the ash and the leachate analyzed. The leachate analysis taken for design purposes was as set out in Table 1.

TABLE 1
"Design" Analysis of Leachate from Power Station Ash

Component or Parameter	Mean Recorded Value	Permissible Values for Industrial Effluent According to: Regulations under South African Water Act	United States EPA, 40 CFR Part 257
pH	11,5+	5,5-9,5	6,5-8,5
Conductivity	760 mSm^{-1}		
Total Dissolved solids*	1800 mg/ℓ+	increase of 500 mg/ℓ above intake	500 mg/ℓ
Total Alkalinity	1260		
Calcium, Ca	600		
Sodium, Na	62	80 above intake	
Potassium, K	7		
Magnesium, Mg	0,1		
Carbonate, CO_3	210		
Hydroxide, OH	275		
Chloride, Cl	75		250
Sulphate, SO_4	320+		250
Nitrate, NO_3	5		10
Fluoride, F	2+	1,0	1,4
Silica, SiO_2	5		
Aluminium, Al	10		
Iron, Fe	0,2		0,3
Manganese, Mn	0,02		0,05
Copper, Cu	0,01	1,0	1,0
Zinc, Zn	0,02	5	5
Cadmium Cd	0,04+		0,01
Molybdenum, Mo	0,5		
Boron, B	1,1	1,0	
Vanadium, V	0,1		
Arsenic, As	0,03	0,5	0,05
Selenium, Se	0,05+		0,01

* All units below this line are mg/ℓ

This is the average analysis for all the specimens subjected to test and represents the material leached by passing one bed volume of water through the ash in a permeameter.

The contents of all constitutents marked + exceed either South African or United States limits for industrial effluent. Examination of the table shows that the leachate did not meet the requirements for an acceptable industrial effluent as far as pH, total dissolved solids, sulphate, fluoride,cadmium and selenium contents were concerned, but was otherwise acceptable.

Tests in which ash/water mixtures were allowed to stand for up to 10 days before analyzing the leachate showed that the limiting solubility of the total dissolved solids was about 1800 mg/ℓ. Repeated leaching of the same specimen showed that the leachate analysis remained sensibly constant even after 10 bed volumes of water had been passed through the ash. Hence it can be expected that the leachate will maintain sensibly the same analysis for a long period of time, after which it should gradually improve in quality, although there is a possibility that the heavy metals will become more mobile if the pH decreases sufficiently.

The main problem appears to be the alkalinity of the leachate and the high sulphate content. Salination of the Vaal River from mining activities to the north, in the Witwatersrand area consists mainly of low pH sulphates, hence the highly alkaline leachate from the ash will not necessarily be detrimental if it finds its way into the river in small quantities.

STRATIGRAPHY OF OPEN PIT SITE

Figure 2 shows a generalized stratigraphic column for the site of the open pit. The coal-bearing Ecca sediments are underlain by two older rock sequences, an ancient glacial deposit, the Dwyka tillite and the even older Transvaal dolomite. It is not certain that the tillite is present over the whole area of the pit but either the tillite or the fissured and jointed, sometimes cavernous and water-bearing dolomite will form the floor of the mine.

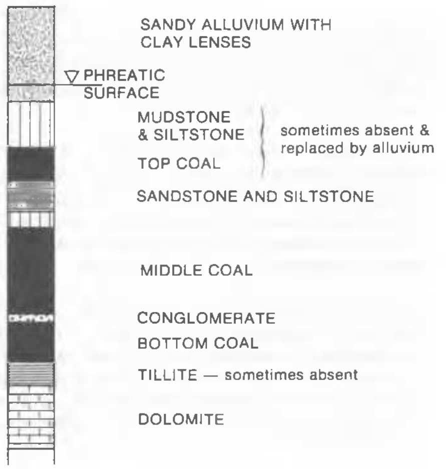

FIGURE 2

Stratigraphic column for site of open pit.

There are three principal coal horizons, with the lower horizons separated by a conglomerate parting that varies in thickness from zero to 3m. The top coal seam is capped by mudstone or siltstone strata that are up to 15m in thickness. However, the meandering of the river has, in places, eroded away both the mudstone and top coal.

The entire mining area is overlain by alluvial deposits of sand, silt and clayey sand, varying in thickness from 4m to 26m, with an average thickness of 15m. The total thickness of coal is up to 40m and averages about 20m. The floor of the open pit will be at an average depth of some 45m below present ground level. Hence once the coal has been removed, and if the ash is not disposed of in the pit, contours of the restored pit surface will be about 10m below present ground level and large areas will be below river level (even allowing for a 33 per cent bulking of the excavated materials).

SURFACE HYDROLOGY AND GEOHYDROLOGY

The mean annual precipitation for the site is 650mm, 85 per cent of which falls in the hot months from October to March. The mean annual evaporation (Symons'pan) is 1570mm, with the maximum evaporation occurring in December and January (185mm) and the minimum in June and July (75mm). The rain falls mostly in short duration storms of high intensity from which there is a large percentage runoff. Most of the runoff from the site of the open pit occurs as sheet flow into the river, although a swampy area collects runoff in the north east corner of the site.

There are two primary aquifers in the area. The sandy alluvium forms an unconfined aquifer with an average saturated thickness of 8m, while the dolomite strata form an underlying confined aquifer. Because of the large macro-permeability of the dolomites and the possibility that they will at least partially form the pit floor, the piezometric surface in this aquifer is of great importance. This surface, established by means of boreholes, is shown in Figure 3. The mean river level is 1420m, a level very similar to the piezometric head in the dolomite.

The phreatic surface in the alluvium is also important as it will affect pre-mining dewatering of the pit over-burden. It also represents an upper limit to the phreatic surface that will be established in the mined-out pit. This phreatic surface is shown in Figure 4.

GROUND WATER IN PIT DURING AND AFTER MINING

During mining, the upper sands will have to be dewatered in the immediate vicinity of the mining face to ensure pit stability. Depending on the permeability of the floor and the presence or absence of a tillite confining layer, inflow will also occur from the dolomites. Once the mining face is far enough away so that it no longer affects the ground water in the backfilled pit, the phreatic surface will re-establish itself.

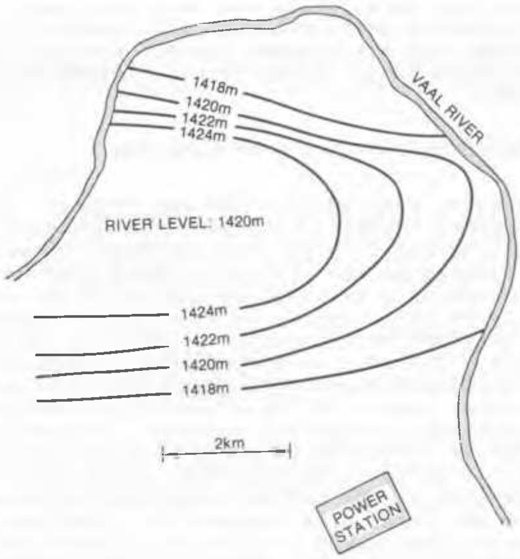

FIGURE 3

Phreatic surface in dolomite aquifer.

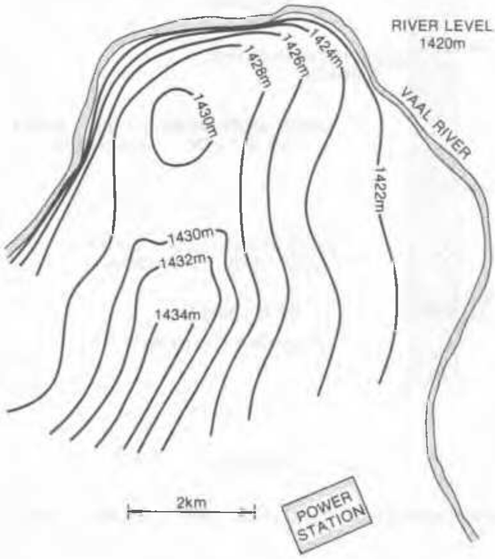

FIGURE 4

Phreatic surface in alluvial aquifer.

Upward seeage from the dolomite, together with lateral seepage from the river will ensure that the re-established phreatic surface is at least at river level. Infiltration of rainfall will tend to raise the phreatic surface above river level.

In the long term, it is unlikely that the present phreatic surface in the alluvium will be exceeded, but the present surface can be taken as an upper limit to the re-established phreatic surface.

PREFERRED ELEVATION FOR STOWING ASH

After being removed from the ash hoppers, it is intended to condition the ash to a moisture content of about 20 per cent in order to minimize dusting as the ash is conveyed from the power station and stowed in the pit. It would clearly be advantageous to stow the ash above the re-established phreatic surface in the mined out pit. The ash would then remain unsaturated, with a reduced permeability and the only leachate generation would come as a result of the limited infiltration through the surface. Studies showed that it will only be possible to stow the ash above the phreatic surface over about two-thirds of the area of the pit and that the thickness of the ash layer will average 12m. The ash layer will be capped by a 2m thick layer of soil and it will be accepted that the remaining one-third of the pit area, or 900 ha will end up at or below the level of the re-established water table. Figure 5 shows the stratigraphic column for the backfilled pit with the ash in the preferred position.

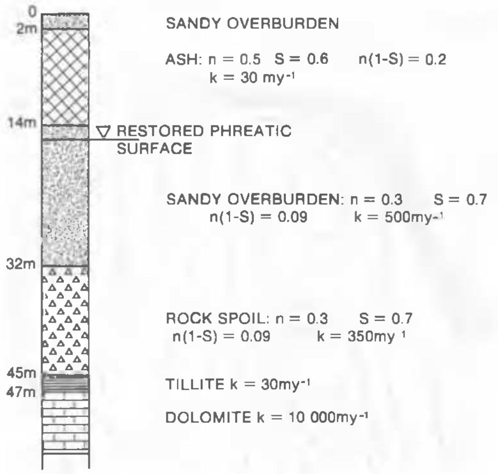

FIGURE 5

Stratigraphic column for backfilled open pit.

TIME TO RE-ESTABLISH PHREATIC SURFACE

The re-establishment time was calculated from the following water balance for the pit area:

inflow to pit = net infiltration from surface
+ upward seepage through pit floor
+ lateral seepage from river.

where:

Net infiltration from surface = precipitation
- run-off
- evapo-transpiration
- lateral seepage into river.

As the pit has lateral dimensions of 5 to 6 km and a depth of only 45m, the lateral flow terms are negligible except around the perimeter of the pit.

The rates of rise of the phreatic surface will depend not only on the rate of water inflow, but also on the volume of air-filled pore space in the backfill. Calculations showed that the rate of re-establishment of the phreatic surface will depend greatly on the permeability of the floor of the pit, as the rock spoil and sandy overburden through which the water will rise are likely to be far more permeable than the pit floor, unless the floor consists of highly permeable dolomite.

The calculations showed that the phreatic surface could re-establish itself in as short a time as 1½ years and was unlikely to take more than 15 years. As the life of the pit is 40 years,the phreatic surface will have fully re-established itself over most of the area of the pit by the time mining ceases.

ESTIMATED SALT TRANSFER TO THE DOLOMITE AQUIFER

Infiltration studies showed that annual net infiltration from the surface is unlikely to exceed 10 per cent of the mean annual precipitation, and will be less if trees having a large water extraction capability, e.g. eucalyptus species, are established on the restored pit surface. Hence the surface infiltration is expected to be less than 65mm per annum. As the permeability of the ash is 450 times larger at 30m per annum, the infiltration term will completely control the generation and movement of leachate from the ash. Over most of the 1800 ha covered by the ash, flow will be vertically downward, and initially, before any leachate penetrates the re-established phreatic surface, the air-filled voids in the ash will have to be substantially filled by the infiltration. It is estimated that this process will take about 20 years from the cessation of dumping in any particular area. There is, however, a possibility that if the ash is carelessly placed on a segregated coarse overburden material, the transfer of salt to the pit floor could take place much more rapidly along paths of preferential flow. Thereafter, there will be a slow downward movement of salt-laden water through the sandy overburden and rock-spoil. If the effects of dispersive flow and attenuation by ion exchange with the soil are ignored, the first salt-bearing leachate will enter the dolomite aquifer after another 50 years, i.e. about 30 years after the pit has been abandoned. The steady-state pollution load is expected to be about 0,1 kg per annum per m^2 of pit area, i.e. a total salt load of 1800T per annum over the 1800 ha pit area.

ESTIMATED SALT TRANSFER TO THE VAAL RIVER

Figure 6 shows the situation along the Vaal River once an adjacent portion of the pit has been mined out. Flow of groundwater is expected to occur through the undisturbed alluvium to the river, once the phreatic surface has re-established itself. Two-dimensional flow analyses showed that the quantity of flow into the river will be very dependent on the permeability of the pit floor. For example, if the floor permeability is 30 my^{-1} flow will be predominantly downwards into the dolomite, whereas if it is only 0,3my^{-1}, almost all the flow will be directed towards the river. It is therefore likely that flow to the river will be highly variable along the river frontage. This variability will be enhanced by the known heterogenity of the alluvium.

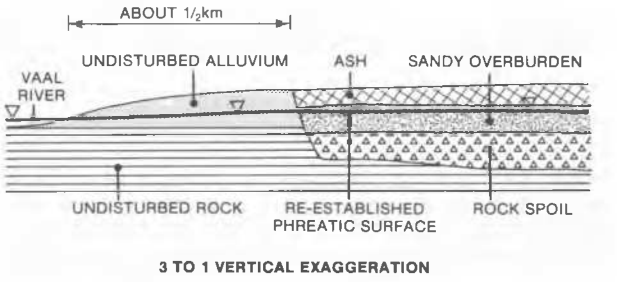

FIGURE 6

Flow from back-filled pit to river.

The best estimate of the salt load that will be discharged into the river under steady-state conditions is between 85 and 170T per annum, over the 18 km river frontage. Allowing for dispersion of the flow, it is estimated that salt will start reaching the river 20 to 30 years after the first leachate reaches the phreatic surface, i.e. 40 to 50 years after the cessation of dumping at a particular point.

Monitoring will be undertaken to check on actual conditions during the life of the pit and after its closure.

COMMENT

The above estimated annual salt loads are considered by the authorities to be acceptable in the light of present pollution loads reaching the river and ground water in the area. The present pollution load reaching the river,from the Witwatersrand to the north, averages 400 000T per annum. Hence, the entire salt load from the ash represents only 0,05 per cent of the present pollution load. Existing salt loads are expected to reduce in future as better control is gained over pollution from mine waste deposits in the Witwatersrand area. However, additional water pollution could have been almost completely eliminated had the surface disposal option been adopted.

ACKNOWLEDGEMENTS

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