The effects of coal mining and energy production in the Šalek valley, Slovenia, on surface water bodies

By Boris STROPNIK[1,3], Marjan TAMŠE[2], Rudi RAMŠAK[3], Alenka DREV ROŠER[3], Peter STEGNAR[1]

[1] "Jožef Stefan" Institut, Ljubljana, Jamova 39, YU - 61111 Ljubljana, Slovenia
[2] RLV - Velenje coal mine, Partizanska 78, YU - 63320 Velenje, Slovenia
[3] ESO Ecological research group, Preloška 1, YU - 63325 Velenje, Slovenia

ABSTRACT

Three surface water bodies or lakes were formed in the Šalek valley, Slovenia, due to the surface subsidence originating from undeground coal mining: lake Škale, lake Velenje and lake Družmirje. Fly ash and products of the desulphurization process from the nearby Šoštanj power plant are deposited in the lake Velenje. Relatively high quantities of certain elements contained in the waste are detoriorating the water quality in this lake, and due to its outflow, in the river Paka is also effected.

In order to restore water quality, the effects of hydraulic fly ash transport parameters were analysed. Tests of fly ash slurry transport and deposition with fly ash to water ratios of 1:10 and 1:1 were performed. The results of these tests show that it is possible to reduce the negative effects of fly ash deposition into the lake by more than 90% by simply applying the appropriate fly ash transport technology.

INTRODUCTION

The Velenje Lignite Coal Mine is an uderground mine 115 years old. Lignite coal is excavated from depths of 270 to 500 m . The coal layer is up to 120 m thick in the central part, 2 km wide and 8 km long. Yearly production is up to 5 million tons. 145 million tons of coal have been excavated during the whole of the mines existence. As a consequence of this exploitation, the terrain over the mine is subsiding by about 90 million cubic metres (total subsidence) or 80m deep in the central part. Half of this is flooded with water. Three lakes were formed there; Velenjsko, Družmirsko and Škalsko lakes, with a total water content of 30 million m^3 and 2 km^2 total surface[(3)].

Table 1: Chemical composition of ash

Concentration	
SiO_2	44 - 56 %
Al_2O_3	16 - 22 %
Fe_2O_3	7 - 22 %
CaO	8 - 14 %
MgO	do 3 %
K_2O	1 - 2 %
SO_3	1 - 7 %
$CaSO_4$	2 - 10 %
Combustible	up to 12 %

The Šoštanj Coal fired plant with an installed electric power of 745 MW consumes up to 4.5 million tons of coal yearly (coal consumption decreasing in the last two years). This represents 85% of the total coal mine production, of which it is estimated only 32% is used effectively. Coal sulphur content is 1.3%. The SO_2 emission factor in the thermal power station is 0.85; the yearly emission of SO_2 is up to 110 000 tons without desulphurization. Ash is separated from flue gases by electrostatic precipitators, which are about 99.5% efficient. Yearly production of ash is around one million tons(1). To prevent dusting, ash is transported, according to the present technology, by water in a slurry with a ratio of 1 to 10 to the ash dump. The average flow-rate is 25 m^3 per minute or 10 million m^3 per year. Water is mixed with ash using ejectors and pumped through the pipeline by centrifugal pumps(3,4).

Ash slurry is transported by two parallel, 2 km long pipelines to a dump close to lake Velenje. During the years 1953 to 1983, the ash slurry flowed directly into lake Velenje. About 13 million tons of ash are deposited in the lake as sediment. Ash disposal technology was changed after the year 1983. Ash slurry sedimentation then started outside lake Velenje in artificial lagoons using ash for outside wall construction. After ash settling, polluted water enters the lake at the same rate as before(3,4).

Since the year 1983 6 million tons have been disposed. The "dry ash dump" is up to 20 m high, 600 m wide and up to 1100 m long with a surface of 430 000 m^2. In the year 1991, ash disposal will decrease to 400 000m^3. According to the chemical composition of the ash, it's disposal represents a few million tons of Si and Al, a few hundred thousand tons of Ca anf Fe and a few hundred tons of U(4). (See ash chemical composition in Table 1.) Extraction of these elements is very difficult, due to its physico-chemical properties.

The surface of lake Velenje increased from 0.25 km^2 to 1.1 km^2 in the last 30 years, while its maximal depth increased from 40 to 50 m between the years 1988 to 1990(3).

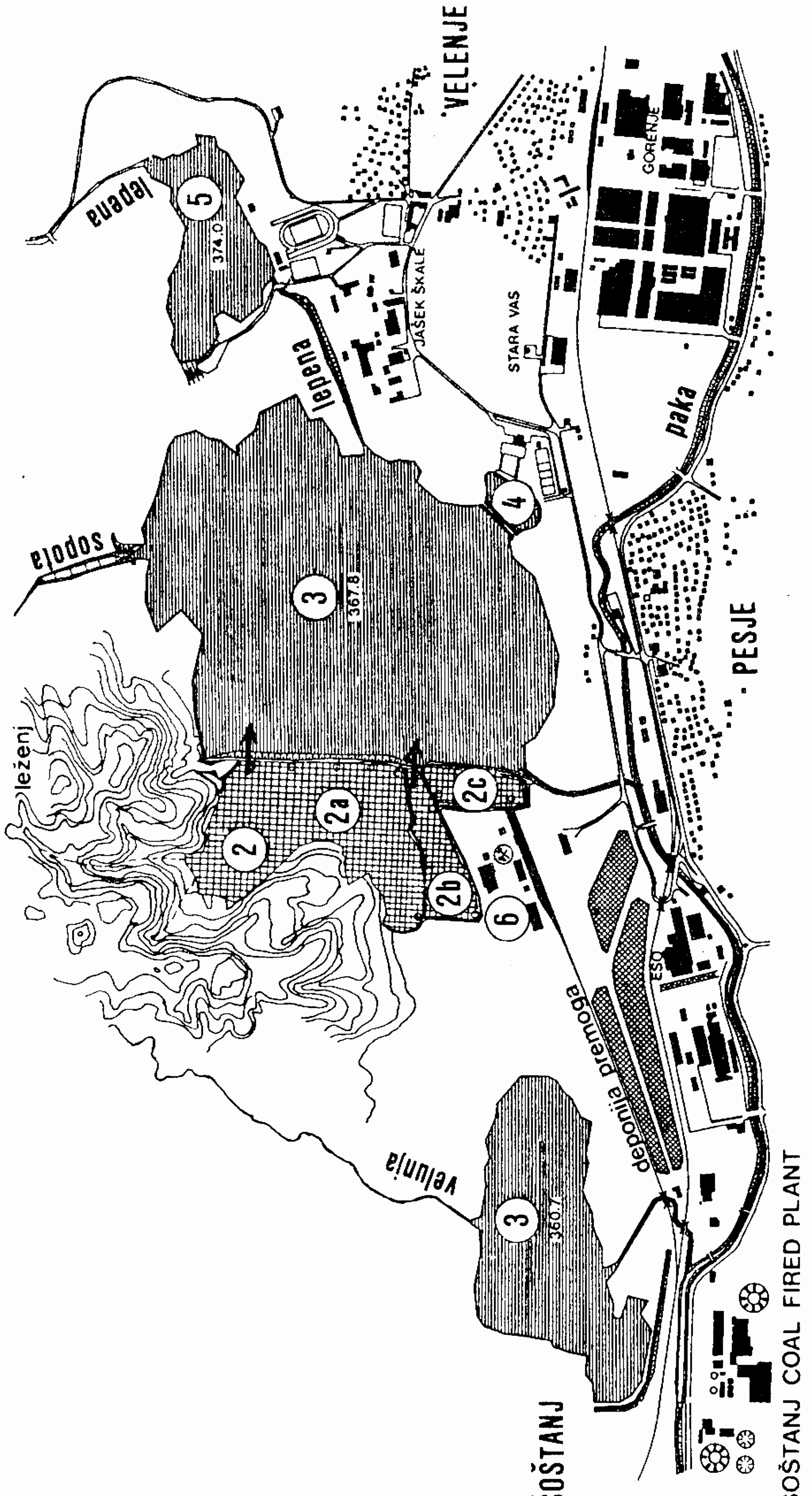

Figure 1: The site of the ash disposal: 1 - lake Družmirje; ash disposal; 2 a, b, c - settlement ponds; 3 - lake Velenje; 4 - lake Tourist; 5 - lake Škale; 6 - Preloge Shaft

ENVIRONMENTAL INFLUENCE OF ASH DISPOSAL

During mixing and transport, water dissolves substantial amounts of alkali and alkaline earth elements from the ash and becomes strongly alkaline. The ratio betwen the concentrations of various cations in lake Velenje water and in the ash after setling are presented in Table 2[1,4].

The lakes look normal except for lake Velenje. It has an abnormally clean blue colour, especially around the effluent from the ash disposal. The thermal power station operates on minimal power during summer. Then slowly life starts in some parts of the lake, especially around natural effluents. Plankton comes mainly from lake Škale which is above lake Velenje. Fish also exist during summer. Before the winter, when the pH slowly increases, fish return to the small rivers Sopota and Lepena; a pH over 9 prevents any life in lake Velenje.

Due to the pH over 9, the lake has the same productivity as an oligothrophic lake. But all the parameters normal are of very different from a typical oligothrophic lake. The oxygen content is very high at all depths of the lake. The temparuture is not normal in the depths, especially over the bottom. The water transparency varies betwen 2m and 13.5m. Plankton in the summer and autumn causes a lower transparency and a dark green colour in the water. In the winter and the early spring, the lake water has a blue to blue - white colour with a high transparency.

Last year the operation of flue gas desulphurization with lime and limestone was begun in Šoštanj thermal power station. Self desulphurization by normal fly ash is up to 30%, due to the alkalinity of the ash. With up to 8% limestone addition to the coal, desulphurization increases up to 50% under optimal condition and increases the total of fly ash CaO from 10% to 20%. This technology causes the lake water pH to increase from 11 to 12. The pH increases with lake depth. The pH value of lake Velenje in different layers down to the bottom during the years 1989- 91 is shown in Figure 2.

Influence of the lake Velenje waters on the river Paka

Efluent from lake Velenje causes a pH increase in the river Paka, decreases the quality of its water and destroys the self cleaning possibilities of the river. In some periods, when the river has a very low water level, the pH increases to over 9. Life processes are then very much disturbed. Over 90% of all bacterial species are then destroyed and self cleaning processes are minimal. Water from lake Velenje causes calcium carbonate deposition in compact form between and on stones. This proces prevents biological regeneration on the stones and increases water transparency.

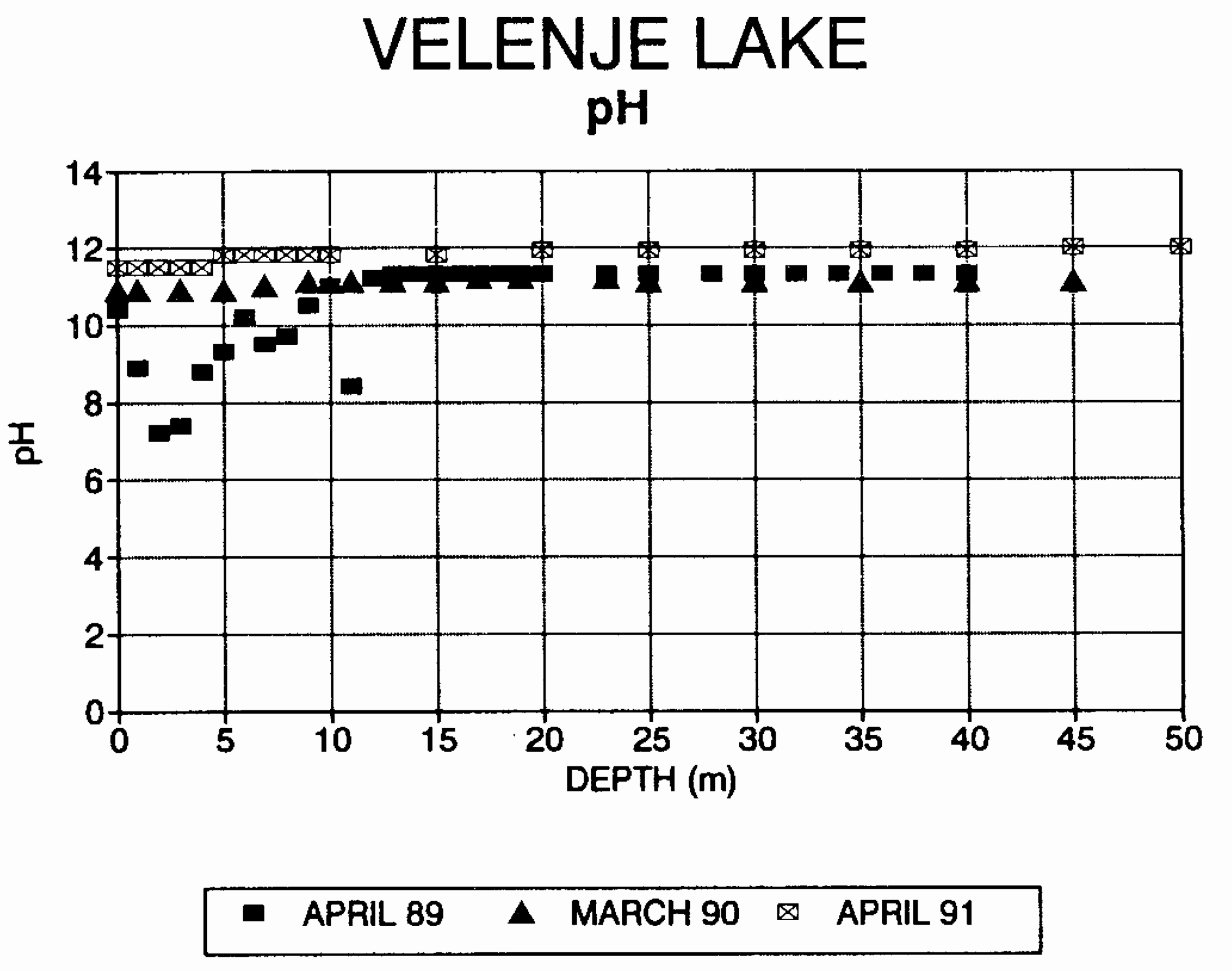

Figure 2: The pH value of lake Velenje in different layers down to the bottom, during 1989 - 91

Transfer of pollutants from the ash deposit

Transfer of pollutants from the ash deposit to environmental water may proceed in three main ways[(1)]:

- The main pollutants in lake Velenje represent water polluted with substantial amounts of alkalies after ash settling.
- Migration of water through the ash layer, dissolving some ash components and carrying them into the lake.
- By diffusion when the water body over the ash deposit is stagnant.

Water polluted with Ca, Na and K hydroxides after ash settling transfers 2500 kg Ca, 1150 Na and 530 K per day from the ash at maximum capacity. This represent more than 95% of the total present pollution.

The migration of water through deposited ash was measured in the laboratory. The ash dump sublayers have very low permeability, between 1.79 to 0.94 $\cdot 10^{-5}$ $g \cdot cm^{-1} \cdot sec^{-1}$[(1)].

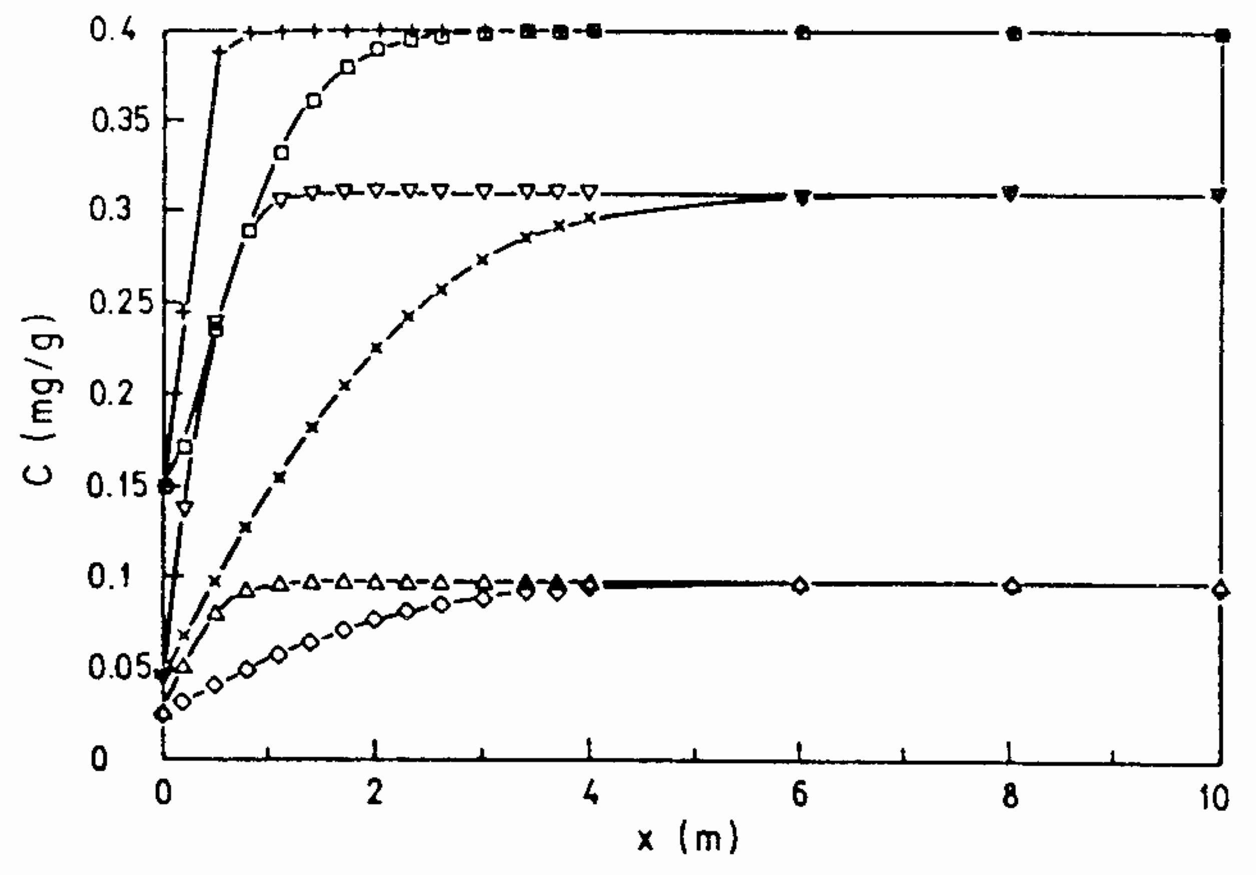

Figure 3: Concentration distribution of calcium, sodium and potasium in the ash layer after 1 and 20 years of leaching.

On the basis of the above results, water leakage from the dump to the lake was estimated. The dump is 1500m long and 500m wide. Since the thickness of the layer is not uniform, a resonable estimate of leakage through this barrier would be 1 to 5 m^3 per day, which represents only 0.33% of the present inflow of polluted water to the lake.

The other way of transferring pollutants from the ash layer to environmental waters is by diffusion. To appraise these processes the diffusion of the most important pollutant ions present such as Ca^{++}, Na^{+} and K^{+} in one year old ash was measured. A sample was taken from the thich suspension ash transportation technology, which has the highest initial concentration of these ions. During the period of a few months, the soluble content of Ca^{++}, Na^{+} and K^{+} decreased more than 10 times as result of the pocolanic properties of fly ash.

Diffusion coefficients were calculated according to these measurements, and to an approximate equation derived from the equation for diffusion from a layer to a solution with a concentration equal to zero. The amounts of leachable material which are removed from deposited ash by diffusion were calculated. Transfer by diffusion from the contact surface ash - lake water is 29 kg Ca, 14 kg Na and 47 kg K per day. This represent 1.1, 1.2 and 8.9 %, respectively, of the total present pollution.

The concentration distribution for different leachable ions in the ash contact surface layer after 1 and 20 years is shown in Figure 3[1].

It is clearly evident from Table 2, which shows elemental concentrations in the lake sediment and water, that the Ca concentration in the lake water is the highest in comparison

Table 2: Concentration of some minor and microelements in the water and sediments of lake Velenje ($mg \cdot dm^{-3}$ water or $mg \cdot kg^{-1}$ dry sediment)

Sample	Na	Ca	Fe	Cu	Zn	Pb	U
WATER							
(Site 1) 19 m deep	29	205	0.02	$\prec$ 0.005	0.02	$\prec$ 0.01	0.0018
(Site 1) 1 m deep	26	142	0.04	$\prec$ 0.005	0.02	$\prec$ 0.01	$\prec$ 0.01
(Site 2) 1 m deep	27	153	0.03	$\prec$ 0.005	0.01	$\prec$ 0.01	0.0023
SEDIMENT							
1.5 m deep	4450	48700	53200	60	300	76	17
RATIO *sediment/water*	153	238	$2.6 \cdot 10^6$	12 000	15 000	7 600	17 000

with the other elements, showing similar concentrations in the water body of the lake more or less independently of the depth where the water samples were collected. After deposition of the fly ash, sediments are formed containing large amounts of different major and trace elements, which are fortunately retained in the sediments due to the binding properties of fly ash and the high pH value in the lake water. Thus diminished elemental migration from sediments to the aqueous phase of the lake occurs[2].

THICK SUSPENSION ASH TRANSPORTATION TECHNOLOGY

This technology of ash removal has been tested in a pilot plant. It was observed that a suspension with suitable properties as far as concerns transport may contain as high as 55% of ash. A piston membrane pump is used in this case for pumping the slurry. The technical characteristics of the pilot plant are the following:

- capacity: 10 to 25 m^3 of slurry per hour.
- transport distance (if horizontal); max 4000 m.
- weight percentage of ash in slurry: 0 to 55%

The pilot plant performance shows the following features in comparison with other hydraulic and mechanical transport and disposal technologies:

- A slurry with more than 50% of ash spills itself over the dump area and hardens after a few days like weak concrete.
- The diameter of the pipes in the pipeline for slurry transport can be smaller for the same ash removal capacity.
- Ash dump stability is satisfactory, and surface is not dusty even in windy conditions (except after the winter period).
- No water drainage at the dump area is needed.
- The dense slurry is also suitable as a back filling in the mine.

CONCLUSIONS

In order to revitalize this particular aqueous environment, the transport and dumping of fly ash should be changed immediately. The posibilities for a closed circulation of polluted water exist with a dry tailings pile located at the edge of the lake.

The best way to decrease water pollution is the eliminaton of the great quantity of polluted water used in transport. On the other hand hydraulic transport is very appropriate for ash dumping. So we are testing the thick suspension technology which is very new for fly ash transportation.

Thick suspension ash transportation technology is very appropriate for fly ash without gypsum as the residue after flue gas wet desulphurization. Fly ash with gypsum additive does not become hard (like weak concrete) on disposal.

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