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Evaluation of water retention on the surface of embankment constructed from the carboniferous waste products

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A b s t r a c t. On the surfaces of embankments of the Goławiecki - stream, constructed by the carboniferous waste products, which were obtained during pit-coal mining at the Piast coal-mine in Bieruń, investigations about evaluation of water retention in surface horizons of the soil were conducted.

The experiments were realized on 4 variants: A - soil, covered with a (0-2 cm) - layer of organic-mineral material; B - soil, covered with a (0-2 cm) - layer of organic-mineral material with biogel - (dose 1); C - soil, covered with a (0-2 cm) - layer of organic-mineral material with biogel - (dose 2); D - soil without the organic-mineral cover. During 2 experimental years in spring and autumn soil samples from several parts of the dike (the southern and northern slope and the top of the dike) were taken for laboratory analyses. Following physical properties were determined: water retention (pF-curve), the saturated hydraulic conductivity coefficient, granulometric composition, the bulk density and the total porosity. Also physico-chemical properties like pH, hydrological acidity and the electric conductivity were determined. The results of the examined water properties of the surface layers of the soil from the embankment show significant differences between the experimental objects.

K e y w o r d s: carboniferous waste products, water retention, saturated hydraulic conductivity coefficient

INTRODUCTION

On the territory of Lower Silesia many embankments of rivers and streams have to be reconstructed, modernized or constructed completely. Needs were particularly visualized during last floods. Lowering of the ground level is caused by hard coal mining and the increase of the height of embankments is thus required. A lot of old embankments have to be modernized as well.

During last few years in the Lower Silesia waste carbonic rock has been used to build hydro-engineering objects. According to the performed research fresh mining material and wastes as well as their storage on the dumps can be the main construction material for engineering embankments [4,12]. However carbonic rock is a very difficult building material, requiring specific technological regimes related to its technical parameters when we consider, e.g., hydroengineering and traffic constructions as well as macrolevelling [3,8,9,13].

When carbonic rock is utilized to the mentioned constructions, prevention from the self-ignition is necessary as well as limiting its negative influence on the environment (dusting, soil and water pollution by eluted salts) [14]. It can be reached by proper consolidation of the rock and biological remediation of the upper layer of the ground [5]. Biological remediation must conform to the technical requirements of the construction. Introduced plants should cover in a very short time the soil surface and form a compact green of a low height, strong vitality and ability to self-reconstruction [1,6]. Roots of the plants cannot penetrate the rock inside the embanks. Increase of water consumption of plants and its better utilization can limit ground flow off [6].

Effects of biological building of the embanks will depend on choosing the proper grass seeds and agrotechnical treatments. Such intervention in cooperation with materials covered the ground and improving its water retention and trophicity allow to receive persevering plant cover of hydrotechnic structures.

METHODS

The field experiment was set in 1998 on an embankment, artificially formed from carboniferous waste products, near Goławiecki stream, situated in the city of Bieruń, in Upper Silesia.

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The experiment was set in four variants A, B, C and D, as well as in the variant '0'.

The experiments consisted of the following variable elements:

- in variant A the ground was covered with a 2 cm layer containing a mixture of organic and mineral matter;
- in variant B the ground was covered with a 2 cm layer containing a mixture of organic and mineral matter, with the addition of a single dose of bio-gel;
- in variant C the ground was covered with a 2 cm layer containing a mixture of organic and mineral matter, with the addition of a double dose of bio-gel;
- in variant D the ground was left completely uncovered.

In all the above variants the embankments were sowed with a mixture of grasses.

In variant '0' the ground was left completely uncovered and not sown with any plant seeds.

Samples were taken for water retention and permeability studies over a period of two years. Samples were taken in variants A, B, C and D, from the southern slope of the embankment, the embankment crown, as well as the upper and lower parts of the northern slope of the embankment, adjacent to Goławiecki stream. In variant '0', the samples were taken from the southern slope of the embankment, the embankment crown, as well as parts of the northern slope of the embankment, due to the variable topography of the terrain. Undisturbed samples were taken by stainless steel Nitshe rings of 100 cm^3 volume. Each sample was taken in 3 repeats.

The following properties were analysed from the obtained material:

- granulometric composition by the Bouyoucose method in Casagrande modification;
- water retention curves (pF curves) in the range pF 0-2 with sand blocks, in the range pF 2-2.9 with sand-kaolin blocks, moisture contents at the matric potential pF 3.7 with Richards mid-pressure apparatus, and Richards high-pressure apparatus at the matric potential of pF 4.2 [7];
- values of saturated hydraulic conductivity coefficient K_{10}, in the range K_{10}<10^{-3}m day^{-1} with the constant head method, while the decreasing failing head method was used for K_{10}<10^{-5}m day^{-1};
- bulk density with the use of gravimetric method for 100 cm^3 soil cores.

The following properties were analysed for general characteristic purposes:

- salinity by the conductometric method according to ISO 11265 norm;
- specific density of solid phase according to ISO 11508 norm;
- reaction (pH) in distilled water and 1 M KCl;
- total porosity calculated out of specific and bulk densities.

Above analyses were conducted only once, after the construction of the embankment.

RESULTS

Granulometric composition

Tested grounds consisted of carboniferous waste rocks with high contents of skeletal parts (ϕ>1 mm) ranging from 60 to 80% approximately (Table 1). These were mainly grain-size particles smaller than 50 mm and large rock crumbs, larger than 200 mm. Disintegration of the large rock crumbs occurred quickly. Smaller fractions appeared more durable.

Soil parts < 1 mm had the granulometric composition of medium clays. The contents of fractions < 0.002 mm ranged from 18 to 19%, fractions < 0.02 mm were from 47 to 50%, and dust fractions (0.02 mm < ϕ < 0.01 mm) ranged from 21 to 23%. The process of change in granulometric composition in regards to soil parts was too slow to be noticed during the experiment.

T a b l e 1. Texture of examined samples

No. of sample	Specification of experiment status	Gravel and stones	Fine particles	Percent of fraction							
		>1	<1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.006	0.006-0.002	<0.002
1	South side of dam	70.3	29.7	8.75	8.75	10.25	9.25	13	17	14	19
2	Top part of dam	60.4	39.6	9.00	9.75	11.00	9.25	11	16	15	19
3	North side upper part	69.8	30.2	11.00	9.30	9.90	9.80	12	16	14	18
4	North side bottom part	76.3	23.7	10.50	10.00	9.50	13.00	9	16	13	19

Other properties

Specific density of a solid phase in the researched carboniferous waste rocks was 2.43 g cm^{-3}. The values of bulk density ranged from 1.16 to 1.63 g cm^{-3}. Most of the volumetric density values fell between 1.3 and 1.5 g cm^{-3}. The total porosity of the researched deposits ranged from 32.8 to 52.8%, with the majority of readings falling within the range of 40 to 50%.

Salinity of the deposits was measured in water suspension in 1:5 proportions and was found to be moderate at 190 - 245 µS cm^{-1}. Reaction was alkaline. Values of pH measured in 1 M KCl ranged from 6.8 to 7.2.

Shapes of water retention curves

Due to high contents of skeletal fractions in the researched material (Table 1) the results of the analyses of water retention curves were characterised by wide dissipation. The curves had irregular shapes despite the fact that the analyses were conducted on three different sample batches and the results were averaged. Therefore, smoothing of shapes of the curves was necessary. This was done using Van Genuchten formulae [15]:

$$\Theta = \frac{1}{\left(1+\alpha|h|^{n}\right)^{m}} \qquad m = 1 - \frac{1}{n} \tag{1}$$

where h denotes the initial potential expressed in cm of column of water, while saturation degree was calculated with formulae:

$$\Theta = \frac{(\theta - \theta_r)}{(\theta_s - \theta_r)} \tag{2}$$

where θ_s denotes maximum water content for a given deposit (at pF=0), and θ_r denotes minimum water content at pF=4.2

Values of constants and were selected at certain levels in order to minimise the sum of squares of differences between the smoothed curve and the experimental points [11].

Samples of curve corrections are presented in Fig. 1. It shows that in some cases the required correction was minimal, while in others the situation was considerably worse.

Relationships between shapes of pF curves and the time period from the beginning of the experiment are presented in Figs 2 and 3, with curves from the same embankment locations (southern slope, embankment crown, upper part of the northern slope and the lower part of the northern slope) joined together.

Variant A (Fig. 2), which had a mixture of organic and mineral matter applied to the embankment in the summer of 1998, showed increased water retention particularly within the small matric potential range.

Variant C, which had a mixture of organic and mineral matter and bio-gel, showed improved water retention at first, but subsequently displayed a gradual decrease in water retention over time, within the entire matric potential range (Fig. 3).

In order to evaluate the influence of particular variants of the experiment on the shapes of the curves, pF curves of different variants describing the same parts of the embankment, in the same time period, were combined on corresponding figures (Figs 4 and 5). The compared data were collected in October 1998 (Fig. 4) and in October 1999 (Fig. 5).

Differences between the remaining variants were insignificant and had to be analysed statistically.

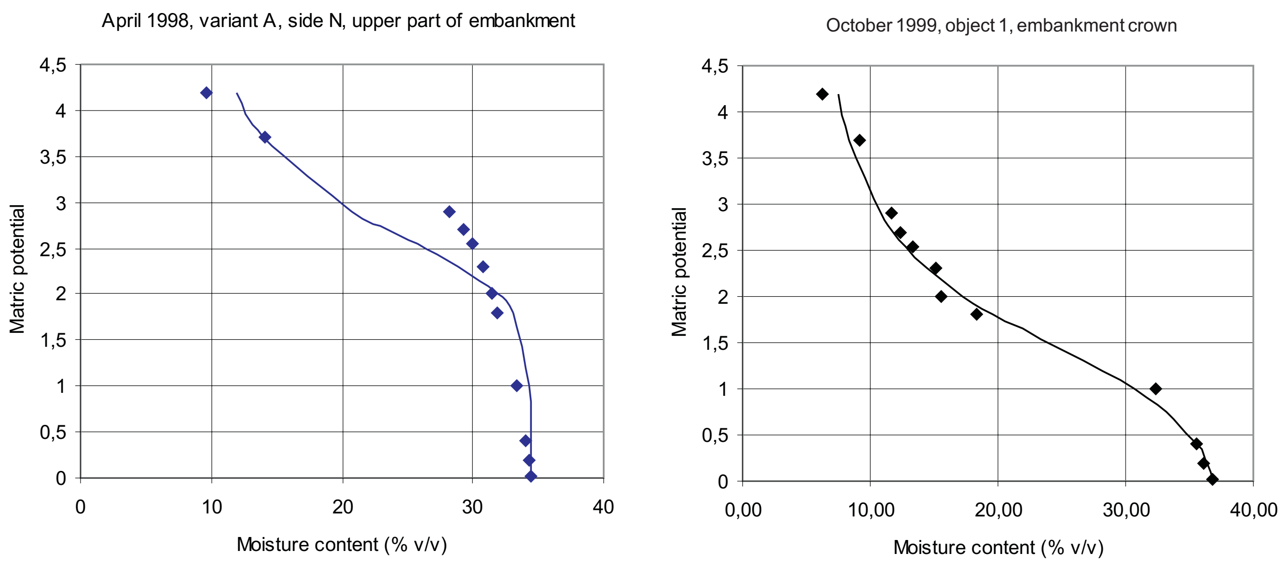


Fig. 1. Differences between the experimental points and curves smoothed with van Genuchten's formulae.

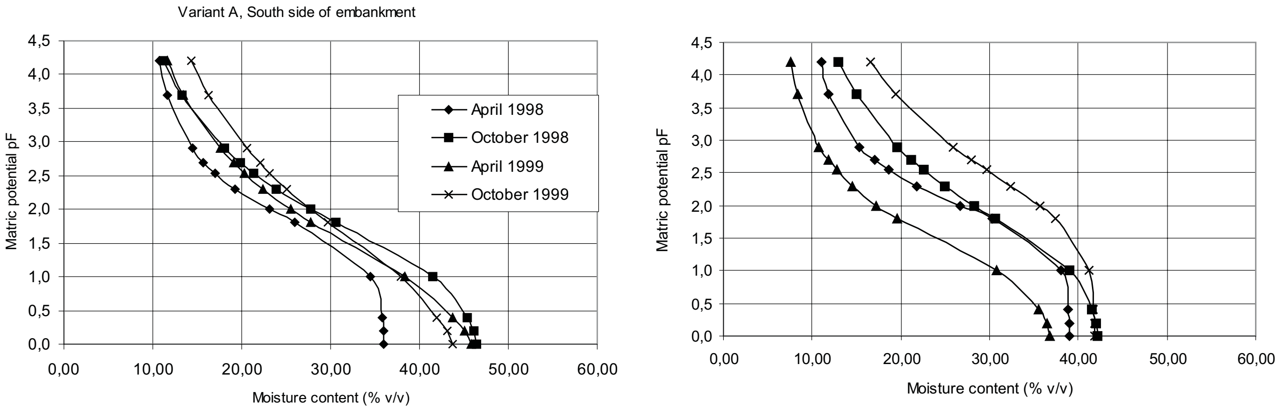


Fig. 2. Relationships between shapes of pF curves and the time period from the beginning of the experiment - variant A.

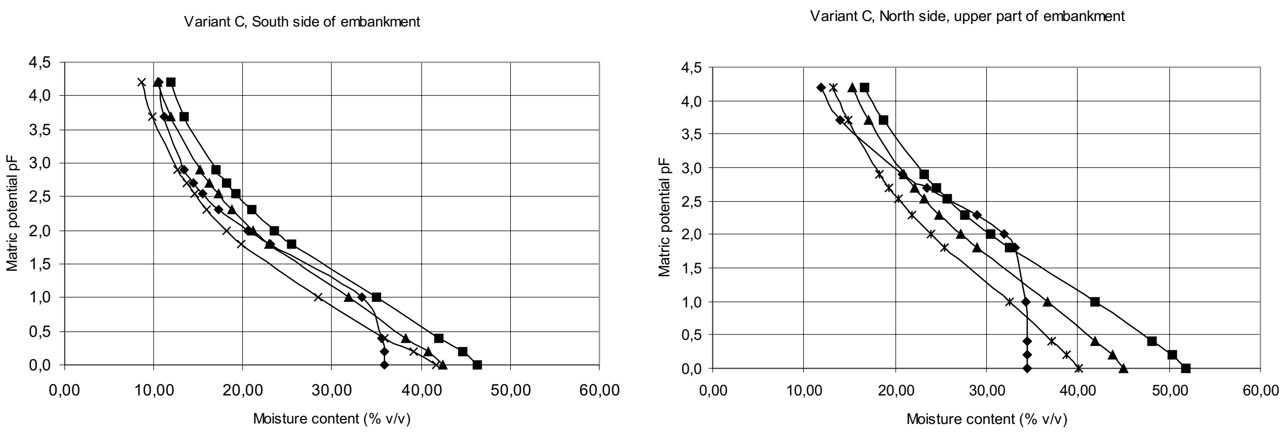


Fig. 3. Relationships between shapes of pF curves and the time period from the beginning of the experiment - variant C. Legend as in Fig. 2.

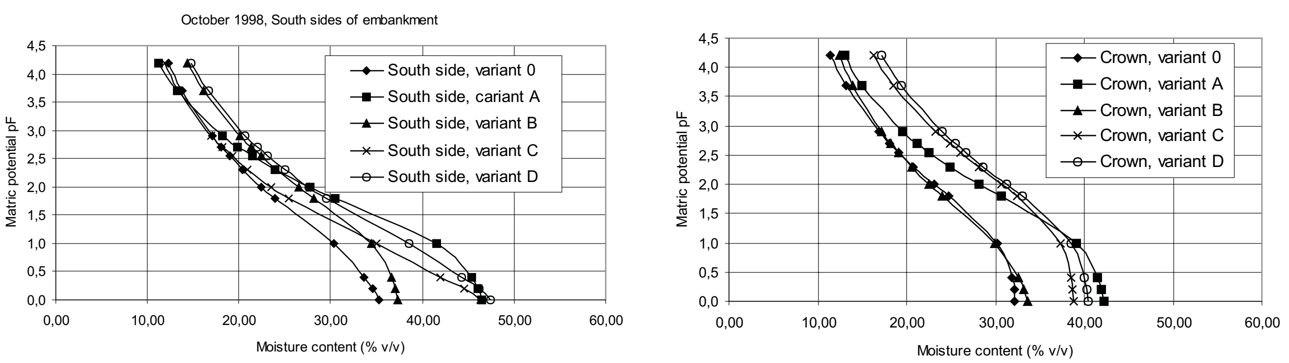
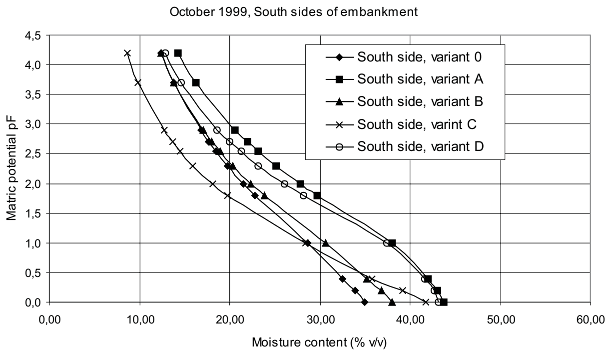


Fig. 4. The shape of pF curves of different variants describing the same parts of the embankment at the October 1998.



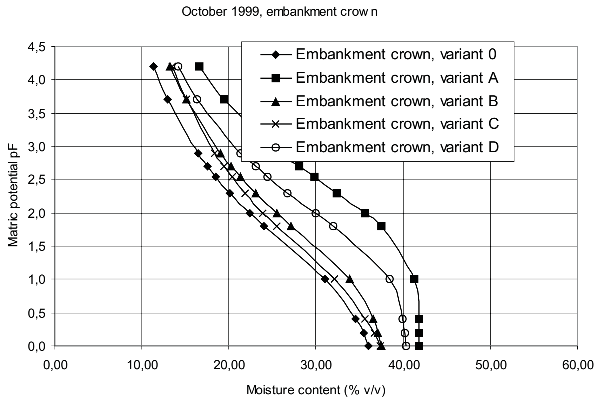


Fig. 5. The shape of pF curves of different variants describing the same parts of the embankment at the October 1999.

Statistical analyses of water retention

Three parameters were selected for statistical analyses. Calculations were based on the shape of the pF curve. They were:

- contents of gravitational water - water bound within the ground with the matric potential smaller than pF 2;
- contents of water available to plants - water bound within the ground with the matric potential greater than pF 2 and smaller than pF 4.2;
- contents of water usable by plants - water bound within the ground with the matric potential greater than pF 2 and smaller than pF 3.7.

Calculations based on the smoothed pF curves

In order to evaluate the influence of the experimental variants on water retention, determinations were made of ratios between the above mentioned parameters in different variants and the corresponding values in variant ‘0’. Calculations of the obtained data were made on three different dates: October 1998, April 1999 and October 1999. Subsequently the results of these calculations were averaged. A hypothesis was tested to ascertain if the results varied from 1 in a statistically significant way.

It was found that the amount of gravitational water in the embankment crown areas did not differ in any way from variant ‘0’.

In the southern slope quantities of available and usable water were higher than in variant ‘0’ in all variants. The differences were statistically significant in a number of cases at levels of α=0.01 or α=0.001.

Gravitational water capacity was higher than in variant ‘0’ in variants A, B and D.

Water retention in the upper parts of the northern slope of the embankment appeared the same as above. The quantities of available and usable water for plants were higher than in variant ‘0’, in variants A, C and D. However, an increase in gravitational water capacity was recorded in variants B and C.

The averages of gravitational water capacity were higher than in variant ‘0’ in all cases, except for the variant A in the upper part of the northern slope.

Gravitational water retention values in deposits covering the lower parts of the northern slope were significantly higher than in variant ‘0’, in variant B only. The averages of retention for gravitational, available and usable water for plants were higher than in variant ‘0’ in all variants. The lack of statistical significance resulted from a small number of samples being taken and wide variances among the results.

Water retention tests conducted in different parts of the embankment and different variants of the experiment have shown that in variant B, the quantities of gravitational water in the upper parts of the northern slope, were significantly higher than the quantities in the southern slope of the embankment. Similarly, in variant C the higher contents of gravitational water were found in the southern slope and upper parts of northern slope of the embankment than at the embankment summit. The lack of consistent and statistically significant differences between different parts of the embankment in selected variants can be explained mainly by the small number of samples available for testing. In order to bypass this problem a hypothesis was tested as to the differences between averages for the contents of gravitational, usable and available water for plants, taking the variants of the entire experiment as consecutive repeats of a single test. It appeared that gravitational water capacity at the summit of the embankment was significantly lower than on the slopes of the embankment. Statistical significance level α was lower than 0.01 in comparison with the southern slope and lower than 0.05, compared with both parts of the northern slope of the embankment.

There were no statistically significant differences concerning the available and usable water for plants between any of the locations.

Calculations based directly on experimental values

Like in the previous case it was found that the amount of gravitational water in the embankment crown areas did not differ in the statistically significant way ($\alpha = 0.05$) in any variants from the variant '0'. The content of available water was greater than in the variant '0' only in the variant D.

In the southern slope, quantities of available and usable water were higher in each variants than in variant '0' but the difference was not statistically significant. The content of gravitational water was grater, in the statistically significant way, than in variant '0' in the variants A and C.

For the samples taken from the upper parts of the northern slope of the embankment the content of gravitational water was higher in each variants than in variant '0'. The difference was statistically significant in the variants B and D. The content of available and usable water were higher than in the variant '0' in six cases but the difference was statistically significant in two cases (usable water, variant A and C).

Gravitational water content in the deposits covering the lower parts of the northern slope were in three cases greater than in the variant '0'. The difference was statistically significant in the variants C and D. The content of available and usable water was in seven cases greater than in variant '0'. The difference was statistically significant for usable water in the variant C and D.

Tests conducted in different parts of the embankment and different variants of the experiment have shown that in variant B, the quantities of gravitational water in the crown of the embankment is lower than in the upper part of northern slope in the statistically significant way. Similarly, in variant C the higher content of gravitational water was found in the southern slope than in the embankment summit. Another differences were not statistically significant.

As we consider the different variants of experiment and times of sampling as a observations we have stated that the content of gravitational water at the embankment crown is significantly lower that at the slopes of embankment. In the cases of available and usable water any significant differences were stated.

Saturated hydraulic conductivity

Water conductivity in the ground in a saturated zone is a significant parameter influencing the quantities of retained water particularly on terrain with variable relief. Water conductivity is expressed by the coefficient K_{10}, which records conductivity of water at a temperature of 10°C. This parameter shows wide diversification, mainly due to the natural variances of soil macropores [2,16]. Nevertheless, statistical analyses of the results allowed a number of justifiable conclusions.

Water conductivity (coefficient K_{10}) of the researched carboniferous deposits, tested directly after the construction of the embankment, was very low. It was lower than the detection level of the laboratory equipment in use. Covering carboniferous waste products with a mixture of organic and mineral substances caused a clear increase in water conductivity. It is worth noting that permeability has also increased in the material situated on slopes of the embankment in variant '0', which was left uncovered (Fig. 6).

Comparisons of averaged water conductivity values, with all readings treated as repeats, indicated increases of this parameter in the winter season of October 1998 - April 1999. These increases were statistically significant at $\alpha = 0.10$ in the crown areas and parts of the southern slope, as well as at $\alpha = 0.05$ on the northern slope of the embankment. While treating results from all locations as repeats, it was concluded that increases in water conductivity in the period from October 1998 to April 1999 were statistically significant at the level of $\alpha = 0.01$. The average geometric value of coefficient K_{10} increased from 1.64 to 16.52 m day^{-1}. It appears that an increase in water conductivity in the surface layer of deposits was caused by the development of grass root systems as well as the phenomena connected with the freezing of water during winter.

Certain conclusions can be drawn from comparisons of water conductivity in different parts of the embankment, while treating all variants as repeats. In all of the test periods, except the initial period, the lowest water conductivity was observed in the crown area of the embankment. The differences between the values of coefficient K_{10}, measured in the crown areas and the slopes of the embankment, were statistically significant in 6 cases at $\alpha = 0.05$, and in 2 cases at $\alpha = 0.1$.

With all samples being taken at different time periods and being treated as repeats, it was concluded that the water conductivity was the lowest in the crown areas of the embankment, with an average value of $K_{10} = 0.234$ m day^{-1}. In

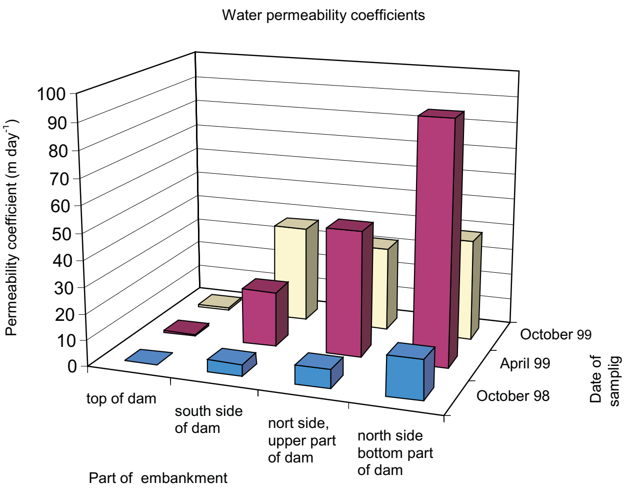


Fig. 6. Geometric averages of water permeability coefficients in a different parts of embankment and a different periods.

the southern slope the average value of coefficient K_{10} was 15.32 m day^{-1}, whereas in the northern slope's upper and lower parts they were 22.21 and 37.41 m day^{-1}, respectively. Differences between water conductivity in the crown areas of the embankment and the values of this parameter in the embankment slopes were statistically significant at $\alpha = 0.01$.

Large dissipation of results, as well as their diversification, which resulted from samples being located in several different areas within the embankment, and the length of time from the embankment construction and having it covered with the deposits, prevented the determination of differences between the individual variants of the experiment. The lowest values of water conductivity (coefficient K_{10}) were in fact observed mostly in the variant '0', but attempts at proving this statistically significant were unsuccessful.

CONCLUSIONS

The analyses of water retention in carboniferous waste products, being the embankment construction materials, in different variants from April 1998 to October 1999, have resulted in certain observations regarding the changes brought about by the application of biological matter, introduced to the top layer in different locations within the embankment.

1. Application of a mixture of organic and mineral matter on top of carboniferous waste products resulted in an increase of water retention particularly noticeable in the range of small matric potentials. Subsequently, water retention has decreased over time within the entire range of matric potentials.

2. An increase in water retention resulted in higher quantities of water available to plants and usable water. This was statistically significant on the slopes of the embankment. It was also apparent to a smaller degree in the crown areas of the embankment.

3. The application of bio-gel resulted in an increase in gravitational water for a short period of time. It was practically unnoticeable after a year's time following the application.

4. Gravitational water retention in the crown areas was significantly smaller than on the slopes of the embankment. This was confirmed after analysing all variants combined together. There were no statistically significant differences noted between the quantities of available and usable water in different parts of the embankment. Statistical analysis based on the smoothed pF curves and directly on experimental values (points pF 2.0, 3.7 and 4.2) generally leads to the same results.

5. Covering the embankment with a layer of organic and mineral matter caused a radical increase in water permeability. Another significant increase in water conductivity was observed after the winter season 1998/1999. The freezing of water and the development of grass root systems on the embankment most probably caused this.

6. Similarly to retention of gravitational water, the water conductivity in crown areas was significantly lower than in both embankment slopes.

7. There were no statistically significant differences found for water conductivity between different variants of the experiment.

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