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REDUCTION OF WATER PERCOLATION THROUGH MINE TAILINGS USING «PMM» MODIFIED GRANULAR MATERIAL: AN EXPERIMENTAL ASSESSMENT

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Abstract

Reducing water percolation through mine tailings is important for limiting water infiltration and the potential migration of contaminants within tailings storage facilities. This study aims to experimentally assess the effect of "PMM" modified granular material on water outflow through a mine-tailings substrate. Laboratory experiments compared a tailings substrate containing "PMM" modified granular material with a control tailings substrate. In each experiment, 4 L of water was applied to the substrate surfaces by simulated rainfall, and the mass of the discharged liquid was measured until the outflow ceased. In all six experiments, the outflow from the "PMM"-containing substrate was lower than that from the control. The cumulative discharged mass was 5,811 g for the "PMM" substrate and 11,240 g for the control, corresponding to an approximately 48.3% reduction in outflow**.** Variability among individual experiments was also associated with unequal intervals between experiments and the resulting differences in the initial moisture content of the substrates due to evaporation. The results indicate that the application of "PMM" modified granular material can substantially reduce water percolation through mine-tailings substrates and provide a basis for further investigation of its hydrophysical properties.

***Keywords**:* mine tailings, PMM modified granular material, water percolation, outflow, filtration, experimental study.

Introduction

Mine tailings are fine-grained residues generated during mineral processing and represent one of the major waste streams associated with mining activities. The increasing volumes of tailings produced worldwide, particularly as lower-grade ores are exploited, create substantial long-term environmental and engineering challenges related to their storage, treatment, and rehabilitation [1, 2]. Fine mineral tailings may contain large proportions of silt-

and clay-sized particles, while their long-term storage can create significant environmental liabilities [1].

Water plays a particularly important role in the environmental behaviour of tailings. Water infiltration and seepage through tailings deposits may contribute to contaminant transport and, in sulphide-bearing materials, provide conditions favourable for acid mine drainage formation [2, 6]. Consequently, limiting the contact of tailings with infiltrating water and controlling water movement through tailings deposits are important components of environmentally sustainable tailings management.

One approach used to control water movement within mine-waste facilities is the application of cover systems designed to reduce net percolation into the underlying waste. Water-balance covers operate principally by storing infiltrating water within the cover material and subsequently returning a portion of this water to the atmosphere through evaporation and evapotranspiration [4]. Their effectiveness therefore depends strongly on the hydrophysical characteristics and water-retention capacity of the materials used.

Recent studies indicate that the hydrophysical behaviour of cover materials can be improved through the incorporation of water-retaining additives. Sun et al. [6], for example, investigated compacted clay modified with clinoptilolite and sodium polyacrylate and demonstrated increased water-holding capacity compared with unmodified material. Their results showed that modification changed the soil-water characteristic behaviour and increased the volumetric moisture content retained at equivalent matric suction. Such findings indicate that modifying a substrate with suitable water-retaining materials can alter its capacity to store water and consequently affect water movement through the material [6].

The hydraulic response of such systems is also influenced by the moisture condition preceding water application. This aspect becomes particularly important under repeated wetting and drying conditions, because water retained within the material and water subsequently lost through evaporation affect the initial moisture state before the next precipitation or water-input event [4, 6]. Consequently, comparative experiments involving repeated fixed-volume water applications can provide useful information on the capacity of modified materials to reduce water passage through tailings under variable antecedent moisture conditions.

In this context, the use of modified granular materials capable of retaining part of the incoming water may provide a practical means of reducing water percolation through mine tailings. However, the effectiveness of such materials must be established experimentally by comparison with untreated tailings under equivalent water-input conditions.

Conflict Setting

The aim of the present study is to experimentally assess the effect of «PMM» modified granular material applied at a rate of 3 kg/m² on water percolation through a mine-tailings substrate. A laboratory experiment was conducted by comparing a tailings substrate containing a 5-cm layer of tailings mixed with “PMM” with an untreated control tailings substrate. Both substrates were subjected to repeated applications of the same fixed water volume, and the discharged liquid was measured until outflow ceased. The study provides a

quantitative experimental assessment of the potential of "PMM" modified granular material to reduce water passage through mine tailings.

Materials and methods

The experimental studies were conducted in the Hydraulic Research Laboratory of the Academician I.V. Yeghiazarov Institute of Water Problems and Hydro-Engineering.

Experimental setup

A laboratory experimental stand divided into three segments was used to comparatively assess water percolation through the investigated substrates. The first segment contained a 5-cm-thick layer of mine tailings mixed with "PMM" modified granular material applied at a rate of 3 kg/m².

The second segment served as a separating section, while the third segment contained a 5-cm-thick layer of untreated mine tailings and was used as the control. The surface areas of the first and third segments were equal, ensuring comparable conditions for water application and outflow measurements.

Fig. 1 Experimental setup for comparative assessment of water percolation through PMM-modified and control mine-tailings substrates

The experimental stand had a longitudinal slope of 4°.

Thus, two substrate variants were investigated:

- PMM substrate – mine tailings containing «PMM» modified granular material;
- Control substrate – untreated mine tailings without «PMM».
-

Experimental procedure

Water was applied to the surface of both substrates by simulated rainfall. During each experiment, a fixed volume of 4 L of water was applied to each substrate. The discharged liquid was collected separately until the outflow ceased.

The mass of the discharged liquid was then determined. The mass of each empty collection vessel was 300 g and was accounted for when determining the discharged liquid mass.

A total of six experimental runs were performed. The same water volume and experimental configuration were maintained for the PMM-modified and control substrates during each run, allowing direct comparison of their response to water application.

The intervals between consecutive experiments were not uniform. Consequently, evaporation occurring during the inter-experimental periods resulted in differences in the initial moisture content of the substrates.

Because the substrates were not brought to a predefined initial saturation or moisture level before each experiment**,** part of the fixed 4L water input replenished moisture lost by

evaporation before the formation of outflow. This factor was considered when interpreting the variability between individual experimental runs.

Data analysis

The effectiveness of the PMM-modified substrate was assessed by comparing the mass of discharged liquid with that obtained from the control substrate. For each experimental run, the relative reduction in outflow was calculated as:

$$R_i = \frac{M_{C,i} - M_{PMM,i}}{M_{C,i}} \times 100$$

where Ri - is the reduction in outflow for experimental run i(%), $M_{C,i}$ - is the discharged liquid mass from the control substrate (g), and $M_{PMM,i}$ - is the discharged liquid mass from the PMM-modified substrate (g).

The overall reduction was calculated from the cumulative discharged masses obtained during all six experiments:

$$R_{\Sigma} = \frac{\sum_{i=1}^{6} M_{C,i} - \sum_{i=1}^{6} M_{PMM,i}}{\sum_{i=1}^{6} M_{C,i}} \times 100$$

This approach was selected because the experimental procedure measured discharged water mass rather than the hydraulic conductivity or filtration coefficient directly. Therefore, the results are interpreted as a comparative assessment of water percolation and outflow reduction caused by the addition of PMM.

Research Results

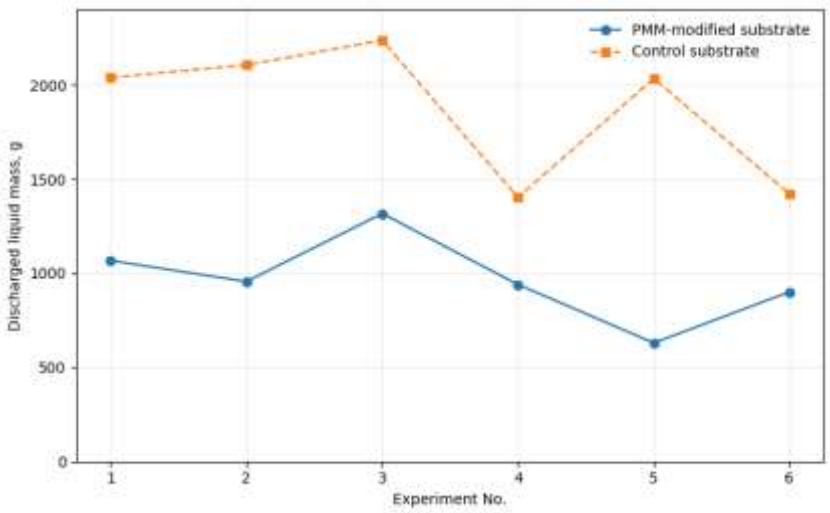
The results of the six experimental runs demonstrate a consistent difference between the PMM-modified and control tailings substrates. In every experiment, the mass of liquid discharged from the substrate containing “PMM” was lower than that from the untreated control substrate. The measured values reported in the experiments are presented in Tab. 1

Table 1

Experimental results and reduction in water outflow

Experiment	PMM substrate, g	Control substrate, g	Reduction, %
1	1067	2039	47.7
2	956	2106	54.6
3	1317	2237	41.1
4	940	1403	33.0
5	630	2034	69.0
6	901	1421	36.6
Total	**5811**	**11240**	**48.3**
Mean	**968.5**	**1873.3**	—

The cumulative mass of discharged liquid over the six experiments was 5811 g for the PMM-modified substrate and 11240 g for the control substrate. Thus, the cumulative outflow from the PMM-modified substrate was approximately 48.3% lower than that from the untreated tailings.



The individual experiments showed reductions ranging from 33.0% to 69.0%**.** Importantly, despite this variability, the direction of the response remained unchanged: the PMM-modified substrate produced less outflow than the control in all six experiments**.**

Fig. 2 Comparison of discharged liquid mass from PMM-modified and control mine-tailings substrates during six experimental runs.

This consistency indicates a systematic effect of the modified material rather than a result driven by a single experimental run. The variation in the absolute outflow values between individual experiments should be interpreted in relation to the experimental conditions. The intervals between consecutive experiments were not equal. Consequently, different amounts of water could evaporate from the substrates between experimental runs, resulting in different initial moisture conditions. Since the substrates were not restored to a predefined moisture or saturation level before each experiment and a constant 4L of water was applied in every run, part of the supplied water replenished the moisture lost during the preceding inter-experimental period. The remaining portion contributed to water retention and outflow. Therefore, variability in absolute outflow between experiments cannot be interpreted solely as variability in the effectiveness of PMM.

For this reason, the paired comparison between the PMM-modified and control substrates within each individual experimental run is particularly informative. Both substrates received the same water volume under the same experimental conditions, while the PMM substrate consistently discharged less water. The observed response is compatible with the general principle underlying water-retaining cover systems, in which increased storage of infiltrating water within a material reduces the quantity available for subsequent percolation [4]. Studies involving water-retaining amendments have likewise demonstrated that modification of a substrate can significantly alter its moisture-retention characteristics and hydraulic behaviour [6].

However, the present experiment did not directly determine saturated hydraulic conductivity or a conventional filtration coefficient. The measured parameter was the mass of liquid discharged after the application of a fixed volume of water**.** Therefore, the observed

48.3% reduction should be interpreted specifically as a reduction in cumulative outflow under the experimental conditions rather than as a 48.3% reduction in the filtration coefficient.

The experimental results nevertheless provide evidence that the addition of "PMM" at 3 kg/m² substantially modifies the water response of the investigated tailings substrate. Further experiments with controlled initial moisture content, fixed intervals between water applications, and direct measurements of hydraulic conductivity would allow the mechanisms responsible for the observed reduction to be quantified more precisely.

Study limitations and further research

The present study provides a preliminary experimental assessment of the effect of «PMM» modified granular material on water passage through mine tailings. The initial moisture content of the substrates was not standardized before each experimental run, and the time intervals between successive experiments were not uniform; therefore, evaporation resulted in differences in antecedent moisture conditions. In addition, the experiments quantified discharged liquid mass rather than hydraulic conductivity directly. Further studies should therefore include controlled initial moisture conditions, uniform intervals between water applications, direct measurements of hydraulic conductivity, and additional PMM application rates to establish the relationship between material dosage and water-retention performance.

Conclusions

The experimental study evaluated the effect of "PMM" modified granular material, applied at a rate of 3 kg/m², on water outflow through a mine-tailings substrate under repeated fixed-volume water applications.

The main conclusions are as follows:

1. In all six experimental runs, the mass of liquid discharged from the PMM-modified substrate was lower than that from the untreated control substrate, demonstrating a consistent effect of PMM on water passage through the investigated tailings.
2. The cumulative discharged liquid mass was 5811 g from the PMM-modified substrate and 11240 g from the control substrate. Thus, under the experimental conditions, the application of PMM resulted in an overall 48.3% reduction in cumulative water outflow**.**
3. The reduction observed in individual experiments ranged from 33.0% to 69.0%**.** This variability was influenced by unequal intervals between successive experiments and the associated evaporation, which resulted in different initial moisture conditions before the application of each fixed 4-L water volume.
4. Since the study measured discharged liquid mass rather than hydraulic conductivity directly, the obtained 48.3% reduction should not be interpreted as an equivalent reduction in the filtration coefficient. It represents a reduction in cumulative water outflow under the specific experimental conditions.
5. The results indicate that "PMM" modified granular material has potential as a water-retaining amendment for reducing water passage through mine-tailings substrates. Further experiments under controlled initial moisture conditions and with direct determination of hydraulic

conductivity are required to quantify its hydrophysical effect and assess its applicability under field conditions.

Overall, the results provide an experimental basis for considering "PMM" modified granular material as a potential component of systems intended to control water movement through mine tailings.

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ՊՈՉԵՐԻ ՋՐԱԹԱՓԱՆՑԵԼԻՈՒԹՅԱՆ ՆՎԱԶԵՑՈՒՄԸ «PMM» ՄՈԴԻՖԻԿԱՑՎԱԾ ՍՈՐՈՒՆԻ ԿԻՐԱՌՄԱՄԲ. ՓՈՐՁԱՐԱՐԱԿԱՆ ԳՆԱՀԱՏՈՒՄ

Վ.Ռ. Գրիգորյան

Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Հանքարդյունաբերական պոչերի ջրաթափանցելիության նվազեցումը կարևոր նշանակություն ունի պոչամբարներում ջրի ներթափանցման և աղտոտիչների հնարավոր միգրացիայի սահմանափակման տեսանկյունից: Աշխատանքի նպատակն է փորձարարական եղանակով գնահատել «PMM» մոդիֆիկացված սորունի ազդեցությունը պոչային սուբստրատի միջով ջրի արտահոսքի վրա: Լաբորատոր ստենդում համեմատվել են «PMM» մոդիֆիկացված սորուն պարունակող և ստուգիչ պոչային սուբստրատները: Յուրաքանչյուր փորձի ընթացքում սուբստրատների վրա անձրևացման եղանակով ավելացվել է 4 լ ջուր և չափվել արտահոսած հեղուկի զանգվածը մինչև արտահոսքի դադարումը: Կատարված վեց փորձերում «PMM» պարունակող սուբստրատից արտահոսքը բոլոր դեպքերում եղել է ստուգիչ տարբերակից փոքր:

Ընդհանուր արտահոսքը կազմել է համապատասխանաբար 5811 և 11240 գ, ինչը համապատասխանում է արտահոսքի մոտ 48.3% նվազմանը: Առանձին փորձերի արդյունքների տատանումները պայմանավորված են նաև միջփորձային ժամանակահատվածների տարբերությամբ և դրա հետևանքով սուբստրատների նախնական խոնավության փոփոխությամբ: Ստացված արդյունքները ցույց են տալիս, որ «PMM» մոդիֆիկացված սորունի կիրառումը կարող է էապես նվազեցնել պոչային սուբստրատի միջով ջրի արտահոսքը և հիմք է ստեղծում նյութի հիդրոֆիզիկական հատկությունների հետագա ուսումնասիրության համար:

Բանալի բառեր. հանքարդյունաբերական պոչեր, PMM մոդիֆիկացված սորուն, ջրաթափանցելիություն, արտահոսք, ֆիլտրացիա, փորձարարական հետազոտություն:

СНИЖЕНИЕ ВОДОПРОНИЦАЕМОСТИ ХВОСТОВ С ПРИМЕНЕНИЕМ МОДИФИЦИРОВАННОГО СЫПУЧЕГО МАТЕРИАЛА «PMM»: ЭКСПЕРИМЕНТАЛЬНАЯ ОЦЕНКА

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Снижение водопроницаемости отходов горнодобывающей промышленности имеет важное значение для ограничения инфильтрации воды и потенциальной миграции загрязняющих веществ в хвостохранилищах. Целью работы является экспериментальная оценка влияния модифицированного сыпучего материала «PMM» на фильтрационный сток через субстрат из хвостов. В лабораторных условиях проведено сравнительное исследование субстрата, содержащего модифицированный материал «PMM», и контрольного субстрата из хвостов. В каждом эксперименте на поверхность субстратов методом дождевания подавалось 4 л воды, после чего измерялась масса вытекшей жидкости до полного прекращения стока. В шести проведённых экспериментах величина стока из субстрата с «PMM» во всех случаях была ниже, чем в контрольном варианте. Суммарная масса вытекшей жидкости составила соответственно 5811 и 11240 г, что соответствует снижению стока примерно на **48,3%**. Разброс результатов отдельных экспериментов также связан с различной продолжительностью межэкспериментальных периодов и обусловленными испарением различиями исходной влажности субстратов. Полученные результаты показывают, что применение модифицированного сыпучего материала «PMM» способно существенно уменьшить прохождение воды через субстрат из хвостов и обосновывают необходимость дальнейшего исследования его гидрофизических свойств.

Ключевые слова: хвосты горнодобывающей промышленности, фильтрация, модифицированный материал PMM, водопроницаемость, сток, экспериментальные исследования.
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