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Influence of Physico-Water and Retention Ability of Chosen Post-Industrial Waste Regarding Natural Use

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ABSTRACT

In the work there were presented results of investigations of physico-water properties and water retention ability of chosen post industrial waste in the aspect of natural management. Soil water characteristic curves were determined in pressure chambers with porous ceramic plate and parametrized to the van Genuchten equation. The obtained results show, that the less advantageous retention ability has flotation waste and coal mud, the medium one metallurgical and soda waste. The best retention properties have energetic and heat energetic waste. The determined soil water characteristic curves can be the base for evaluation possibilities of natural management of the investigated waste. The carried out investigations, supplemented by examination of chemical properties enable to choose optimal methods of biological reclamation of landfills where are deposited.

Keywords: industrial waste, soil water characteristic curve, natural waste management.

INTRODUCTION

Man activity often leads to durable changes in nature. One of the greatest threats of Earth Surface, beside water contamination, is soil degradation, caused by depositing of various kind of industrial waste [Klatka et al., 2016], particularly coming from coal mining [Klatka et al., 2015; Mayo et al., 2023], metallurgy and power engineering [Bell and Donnelly, 2006; Sas-Nowosielska et al. 2010]. It is difficult to reduce the negative effects of the both phenomena, but thanks to series activities concerning recovery of destroyed soil its former natural value and it enables further land use, in changed shape. According to data of Statistics Poland (2023), in Poland there were produced 107.7 tons of industrial waste. The main sources of waste were like in the previous years: coal mining and industrial processing. Waste collected in landfills regarding the origin, can be in various degree threat the natural environment [Jurczyk and Koc-Jurczyk, 2014]. The problems with acquiring of new areas for location of landfills force to elaboration new methods of waste management [Gilewska, 2006]. Stone coal is the base energetic fuel in Poland, what makes that waste amount produced by mining industry will be still main and prevailing source of industrial waste [Boroń and Klatka, 1999]. Among post-mining waste prevail the one created during searching and mineral mining and from flotation of coal enrichment. Other industry branches, as for example energetic, chemical or steel metallurgy produce great amount of post-production waste as well, that are collected on landfills. In Poland the industrial waste are used very occasionally, for example energetic or metallurgy, for reclamation of landfills of other waste, mainly mining [Strzyszcz and Łukasik, 2008]. In the framework of reclamation of these landfills however increasingly there are used substrates created on the basis of based on mixture of various kinds of waste [Halecki and Klatka, 2017]. The important stage in the completely arrangement of problem of rational waste management in Poland was The Waste Act of 14 December 2012 r., amended in the year 2022 [Dz.U. 2022 poz. 2151]. Because industrial waste are characterized by disadvantageous properties influencing on proper growth and development of plants [Vega et al., 2006], in the stage of natural management, series of laboratory investigations of physical, water and chemical should be carried out. Regulation of the Environment Ministry of 1 September 2016 in the matter of way of conductance of contamination evaluation of the Earth surface [Dz.U. 2016 poz. 1395] regards mainly chemical properties, ignoring water properties, that full reflection is soil water characteristic curve (SWCC). Proper water content in waste and retention properties are the main agents necessary for proper development and life of plants in the biological reclamation. The aim of the work was analysis of physico-water and retention properties of chosen industrial waste in the aspect of natural management.

METHODS

The investigations covered eight materials: two kinds of post-mining waste, industrial waste: power station waste, thermal power plant waste, metallurgical waste and soda waste, as well as two substrates created with mixing of various waste. The first post-mining waste was the material from flotation coal enrichment. In its composition occurs great amount of clay separate below 1 mm [Halecki and Klatka, 2017]. The second material were post-mining muds, washed, processed in easy transportable granule. The second material were coal muds, washed, processed in easy transportable granule. The waste underwent recycling and partially were used for reclamation of degraded areas by coal mining exploitation. The samples for laboratory investigations were taken on the areas of processing plant in Zabrze. The remaining materials constitutes: power plant waste, taken from the waste landfill in Przezchlebie near Gliwice, heat plant waste from the Power and Heat Plant “Łęg” in Cracow taken in landfill “Mogiła” in Cracow, metallurgical waste from the landfill of the Sendzimir Steelworks in Pleszów near Cracow and post-sodium waste from landfill of the former Cracow Soda Plant “Solvay” [Boroń et al., 2010]. Location of sampling points is presented on Figure 1.

The first substrate was mixture of sewage sludge, post-mining quarry stone and ash from heat power station in percentage respectively. The second substrate was mixture of coal muds (30%), sewage sludge (35%), post-mining quarry stone (20%) and ash from heat power station (15%). The substrates were produced in laboratory by mixing the proper components in the above proportions. The materials have codes assigned by the Waste Act [Dz.U.2023.1587] and did not classified as waste dangerous for environment. The recycling by creating of substrates, is the proper process and important component of circularity management [Łabętowicz et al., 2019]. The used sewage sludge meets requirements that are put to sewage sludge used for reclamation of areas for non- agricultural purposes [Halecki and Klatka, 2018]. As part of the laboratory investigations

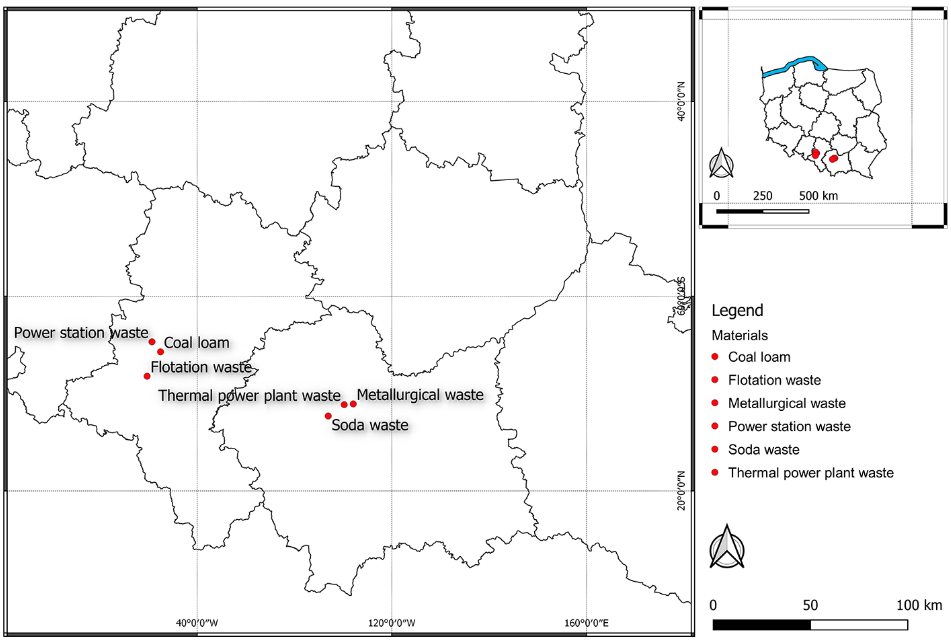

Figure 1. Sampling points

there were determined: chosen physical properties, saturated hydraulic conductivity and water characteristic curve. The investigations were determined according to procedures used in evaluation of ground suitability for in reclamation and the methods used conventionally in soil science [Namiernik et al., 1995; Mocek et al., 1997]. Specific density (SD) was determined by picnometric method in distilled water. Bulk density (BD) was determined by means of rings, of volume 100 cm^3. Total porosity (n) was calculated as:

$$n = 1 - \frac{BD}{SD} \text{ (-)} \quad (1)$$

Among the total porosity (n), coarse porosity (CP) (Ø >2.5 µm), medium porosity (MP) (8.5–0.2 µm) and fine porosity (FP) (Ø<0.2 µm). Calculations were performed based on the equations:

$$CP = \frac{\theta_s - \theta_{2.5}}{\theta_s} \cdot 100 \text{ (\%)} \quad (2)$$

$$MP = \frac{\theta_{2.5} - \theta_{4.2}}{\theta_s} \cdot 100 \text{ (\%)} \quad (3)$$

$$FP = \frac{\theta_{4.2}}{\theta_s} \cdot 100 \text{ (\%)} \quad (4)$$

Saturated hydraulic conductivity was determined using the pressures decrease in the device based on the Darcy law, with adjustable high of water table and electric record of water volume. Water characteristic curve was determined in pressure chambers (the Richards apparatus) [Kowalik, 1972] (Figure 2). Evaluation of retention ability of the chosen waste was carried out based on the parametrized van Genuchten equation [Wösten and van Genuchten, 1988; Boroń and Ryczek, 1999]:

$$\theta_v = \theta_r + (\theta_s - \theta_r) \cdot \left[(1 + |\alpha \cdot h|^n)^{(\frac{1}{n}-1)}\right] \text{ (cm}^3\text{cm}^{-3}\text{)} \quad (5)$$

where: θ_v – volumetric water content [cm^{3}cm^{-3}], h – matrix potential [cm], θ_r – residual volumetrwater content [cm^{3}cm^{-3}], θ_s – staurated volumetric water content [cm^{3}cm^{-3}], α [cm^{-1}] and n [-] – parameters.

Based on the water characteristic curves the following characteristic points were determined:

- field water capacity (pF = 2.5);
- critical point (pF = 3.2);
- permanent wilting point (pF = 4.2).

And the retention capacities were calculated in the layer 1 m, as:

$$EAWC = (\theta_{2.5} - \theta_{3.2}) \cdot h \text{ (m)} \quad (6)$$

$$DAWC = (\theta_{3.2} - \theta_{4.2}) \cdot h \text{ (m)} \quad (7)$$

$$TAWC = (\theta_{2.5} - \theta_{4.2}) \cdot h \text{ (m)} \quad (8)$$

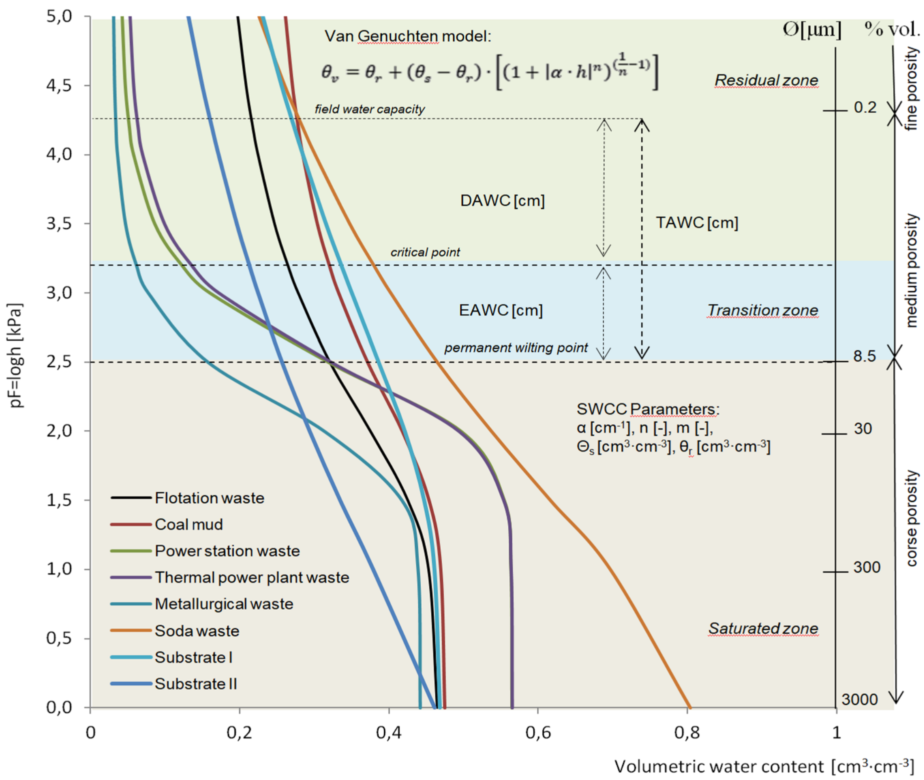

Figure 2. Scheme for the van Genuchten soil water characteristic curve (SWCC) model for the investigated materials

where: *EAWC* – easy available water content, *DAWC* – difficult available water content, *TAWC* – totally available water content, $\theta_{2.5}$ – volumetric water content at field water capacity, $\theta_{3.2}$ – volumetric water content at critical point, $\theta_{4.2}$ – volumetric water content at permanent wilting point.

RESULTS AND DISCUSSION

Among the investigated materials, flotation waste, coal mud, heat power and metallurgical waste as well as substrates had values of bulk density similar to the ones occurring in mineral loamy, clay and silt soil in Poland, regarding the structure, fluctuating between 0.90 and 1.60 Mg·m^{-3} [Mocek, 2015]. The similar results for coal muds obtained Doniecki and Siedlecka [2006], which show, that this material is characterized by good physical properties. Power and soda waste have much more lower values of bulk density (mean 0.54 Mg·m^{-3}). The highest values of bulk density have substratum 1, substratum 2, metallurgical and heat power waste. In turn the lowest value has power waste (Table 1). Total porosity conditions air-water ratios, that to a high degree decide of possibility of natural management of a given waste. As the most optimal system it is regarded the one having value of total porosity about 50% [Mocek, 2015]. In a case of the investigated materials one can state, that almost all are characterized by optimal level of total porosity. The exception are soda and power waste. In a case of substrates, the lower values of total porosity had substratum 2. It can be connected with supplement of coal mud. It is confirmed by the investigations carried out by Balaweider and Marciniak-Kowalska [2007], which analyzing possibilities of use of waste for production of bricks, showed decreased values of total porosity with supplement of flotation waste. Air-water properties depends however not only on total porosity, but above all on participation of particular kinds of pores. In macropores air and water mover around freely. In medium and micropores movement of air is hindered, while water movement takes place under influence of capillary forces. Coarse grain systems, where macropores prevail, are characterized by high permeability, are breezy, but too dry. Fine grain systems, of medium and micro pores, with advantage of medium and macro pores, can store great amount of water, show low permeability and are not too breezy. The most advantageous air-water properties show grain systems, in which prevail medium pores, with moderate participation of micro and macropores [Mocek, 2015]. In the investigated samples, medium pores dominated in energetic and heat energetic waste (about 47%). Participation of macro pores was prevailing in metallurgical waste (64%), in soda waste and in substrate (by 40%), while micro pores dominated in flotation waste (about 47%), coal muds and in substratum 1 (by about 58%). The determined filtration coefficient showed, that the highest permeable is coal mud, that value amount about 4.3 m·d^{-1}, what allows to classified it according to Soil Survey Division Staff [1993] to high class of filtration. This fact results from production technology of this material, that is transformed in easy transportable granule. The lowest value of filtration coefficient attained soda and energetic waste, what allows to classify the waste to medium filtration class (Table 1). Values depends, similarly as physical properties on texture of the investigated materials, what was discussed by Ryczek et al. [2007] and Boroń et al. [2010]. In a case of the investigated substrates the value of filtration coefficient is determined mainly by content of coal quarry stone.

The lowest value of volumetric water content in the field water capacity point ($pF_{2.5}$) was stated for metallurgical waste and amounted 0.159 cm^3·cm^{-3}. The highest value in turn was noticed for soda waste: 0.465 cm^3·cm^{-3}. Volumetric water content in critical point (beginning of water uptake braking) ($pF_{3.2}$) was between 0.061 cm^3·cm^{-3} for metallurgical waste and 0.380 cm^3·cm^{-3} for soda waste. In the permanent wilting point ($pF_{4.2}$) the lowest value had metallurgical waste, while the highest one soda waste and attained respectively 0.034 and 0.284 cm^3·cm^{-3}. Water capacities corresponding total available water (TAWC) for the investigated waste amounted between 5.2 cm for coal mud and 19.8 cm for energetic waste. Water capacities corresponding easy available water capacity (EAWC) amounted between 9.4 cm for coal mud and 26.9 cm for energetic waste. Water capacities corresponding difficulty available water capacity (DAWC) amounted between 2.7 cm for metallurgical waste and 9.6 cm for soda waste. Such values are lower than the ones stated for post-mining areas undergo reclamation [Szafrański et al., 2011]. The lowest advantage retention properties have flotation waste and coal mud (Figure 3). According to Strzyczcz and Łukasik [2008], the waste can be however used in reclamation of

Table 1. Physical properties and saturated hydraulic conductivity coefficient

Material	Bulk density Mg·m^{-3}	Specific density Mg·m^{-3}	Filtration coefficient m·d^{-1}	Total porosity % obj.			
				Coarse >8.5 μm	Medium 8.5–0.2 μm	Fine <0.2 μm	Total
Flotation waste	1.31	2.04	2.36	17.84	13.10	27.08	58.02
Coal loam	1.25	2.09	4.28	13.14	11.99	35.47	60.60
Power stadion waste	0.95	0.52	1.23	16.63	18.33	3.54	38.50
Thermal power plant waste	0.91	2.48	1.64	24.39	26.52	6.50	57.41
Metallurgical waste	1.36	2.42	2.36	32.39	14.31	3.89	50.59
Soda waste	0.56	1.05	0.56	13.71	7.32	11.48	32.50
Substrate 1	1.62	2.68	2.36	9.14	12.60	30.42	52.16
Substrate 2	1.13	2.09	3.26	21.75	10.13	17.27	49.15

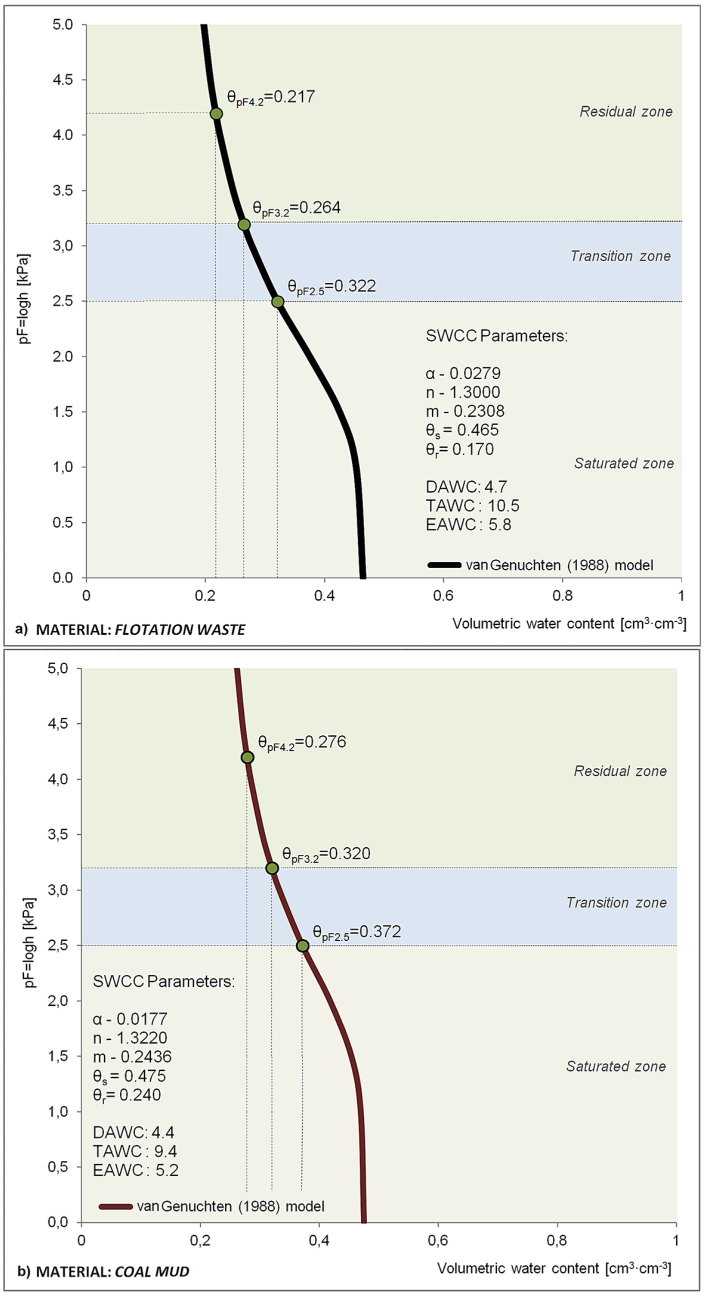

Figure 3. Soil water characteristic courves for coal waste: (a) flotation waste, (b) coal mud

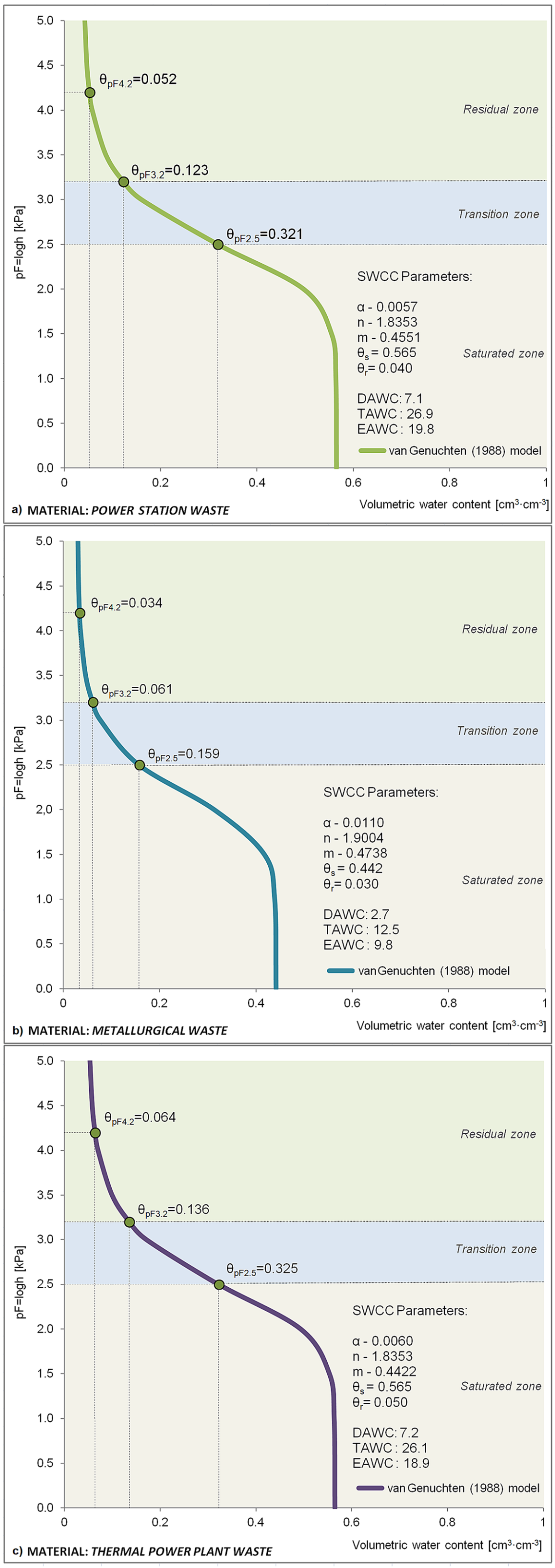

Figure 4. Soil water characteric curves for energetic (a), metallurgical (b) and heat energetic waste (c)

post-mining waste, in which prevail fraction of granulation 30–250 mm. In this case they should be mixed with upper layers of dumped material. It should be emphasized that they have to meet standards determined in Regulation of Environment Ministry of 1 September 2016 in the matter of way of performing evaluation of Earth Surface contamination [Dz.U. 2016 poz. 1395] for grounds used in reclamation. The mean retention properties have metallurgical and soda waste. The first one had most often advantageous composition and chemical properties for plants [Strzyszcz and Łukasik, 2008]. In turn, soda waste taking into account alkaline reaction and high level of salinity, that measure is electrical conductivity, are characterized by disadvantageous properties and constitutes high challenge in the stage of natural management [Boroń et al., 2016]. The best retention properties had energetic and heat energetic waste. Regarding high content of silt separate, the waste are however exposed to wind erosion. In the stage of their reclamation, the post-coal waste can be used, mixing it with the ground, what safeguards against silting and improves initial conditions of biological reclamation [Strzyszcz and Łukasik, 2008]. The determined SWCCs for coal mud and flotation waste are similar, likewise the SWCCs determined for metallurgical, energetic and heat energetic waste (Figure 4). It was connected with low differentiation of grain size of these waste.

The determined SWCCs for the investigated substrates have similar shape to the ones presented for mineral soils in Poland of high content of clay separate [Mocek, 2015]. The comparable shape was obtained as well as for soda waste (Figure 5). This fact should be connected with high content of clay separate, in the case of soda waste – clayey silt [Boroń et al., 2016], while for substrates – content of ash from heat energetic power.

In the natural conditions, soil is characterized by high differentiation of water storage occurring in the profile and various possibilities of supplementation or removement of surplus. Plants growing on such soils can have sufficient amount of water for proper growth, or suffer because of scarcity as a result of other factors, for example texture. That is why evaluation of influence of full availability of water on plant growth conditions should regard not only depth of its occurrence, but mobility and chemical composition as well as. High values of specific electrical conductivity recorded for soda waste and the investigated substrates [Boroń et al., 2016; Halecki and Klatka, 2017] show high concentration of soluble salts manifesting

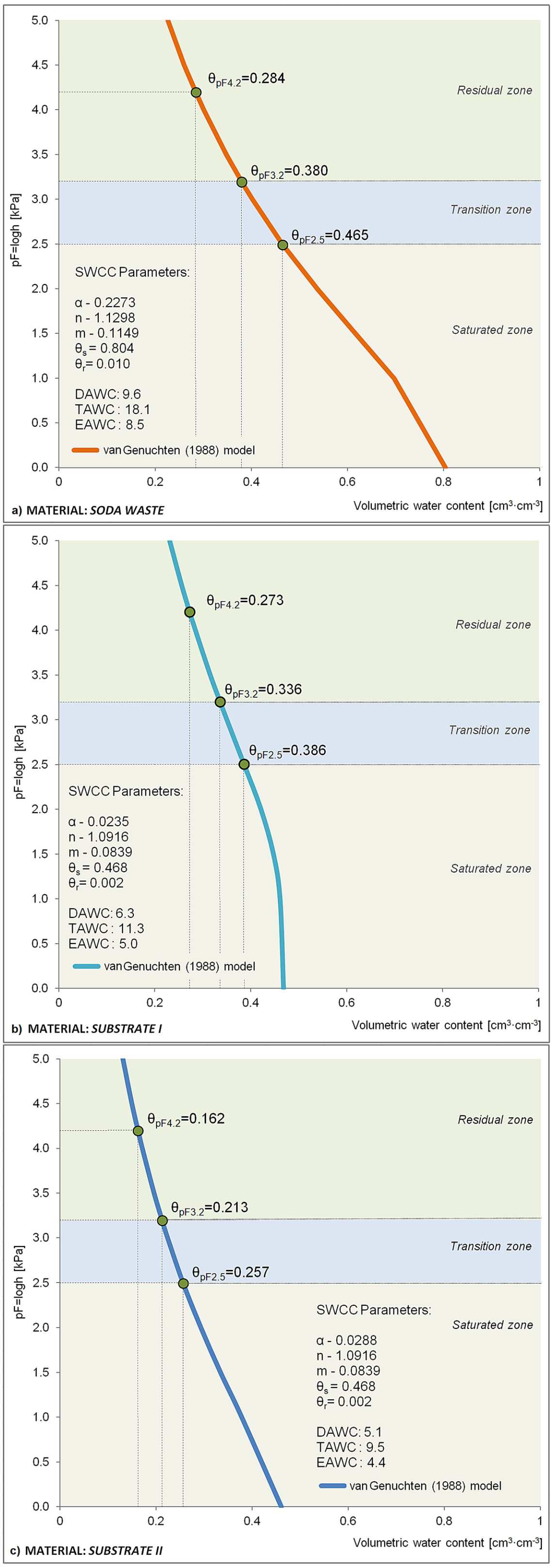

Figure 5. Soil water characteristic curves for soda waste (a), (b) substrate I and (c) substrate II

increase osmotic pressure in soil solution. In the case of the investigated materials it causes decrease availability of water for plants.

CONCLUSIONS

The determined physical properties of the investigated waste are similar to the ones occurred the most often in loamy, clayey and silty soils in Poland. The exceptions are power station waste and soda waste. Also, almost all of the investigated materials are characterized by optimal values of total porosity. The determined filtration coefficients allow coal mud to be classified in the high filtration class, which is related to the production technology of this waste. The lowest value of the filtration coefficient was obtained for soda waste and power station waste, which were classified in the medium filtration class. The values of the filtration coefficient of the tested materials depend, like the physical properties, on their granulometric composition. The lowest values of volumetric water content at the point of field water capacity ($pF_{2.5}$) was observed for metallurgical waste, while the highest was recorded for soda waste. The volumetric water content at the critical point ($pF_{3.2}$) was the lowest for metallurgical waste, and the highest for soda waste. At the point of permanent wilting point ($pF_{4.2}$), the value was lowest for the metallurgical waste while the value was highest for the soda waste. The coal mud was characterized by the lowest reserve of water corresponding to totally available water content and easy available water content, while the highest values were recorder for power station waste. In turn, water storage corresponding to difficult available water content was the lowest for metallurgical waste and the highest for soda waste. Based on the carried out investigations, it was stated, that the lowest advantageous retention properties are characterized by flotation waste and coal mud. The medium retention properties had metallurgical waste and soda waste. The best retention ability showed power station waste and thermal power plant waste. The determined physico-water properties and retention abilities of the chosen industrial waste can be the base for evaluation of possibility of their natural management. Complemented by studies of chemical properties, they will fully enable the selection of optimal methods of biological reclamation of landfills on which they are deposited.

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REFERENCES

1. Balaweider M., Marciniak-Kowalska J. 2007. Research into the possibility of using waste to make bricks (in Polish). Górnictwo i Geoinżynieria., 31(3/1), 49-52.
2. Bell F.G, Donnelly L.J. 2006. Mining and its impact on the Environment. Taylor & Francis. New York, USA.
3. Boroń K., Klatka S. 1999. Evaluation of farmland degradation induced by coal mine activity. 10th International Soil Conference, May 23–28, 1999, Purdue University, USA, 118–121.
4. Boroń K., Klatka S., Ryczek M., Koperski T., Lech B. 2010. Reaction and electrolytic conductivity of chosen coal mine waste used in land reclamation (in Polish). Ochr. Środ. Zasob. Natur., 41, 385–390.
5. Boroń K., Klatka S., Ryczek M., Liszka P. 2016. The formation of the physical, physico-chemical and water properties reclaimed and not reclaimed sedyment reservoir of the former Cracow Soda Plant „Solvay" (in Polish). Acta. Sci. Pol., Formatio Circumiectus, 15(3), 35–43.
6. Boroń K., Ryczek M. 1999. Hydraulic conductivity in unsaturated zone of silt and ash. Proc. of the International Symposium on Advances in water science, vol. I: Physics of soil water. StaraLesna, Slovakia.
7. Boroń K., Klatka S., Ryczek M., Zając E. 2010. Reclamation and cultivation of Cracow soda plant lagoons, s. 245-250. In: Construction for Sustainable Environment. Sarsby & Meggyes, CRC Press Taylor & Francis Group London, A Balkema, 245-250.
8. Doniecki T., Siedlecka E. 2006. Waste coal silt as part of mineral insulation of landfills (in Polish). Górn. Geoinż., 30(3/1), 41–46.
9. Gilewska M. 2006. Use of waste in reclamation of post-mining land and ash dumps (in Polish). Rocz. Glebozn., LVII(1/2), 75–81.
10. Główny Urząd Statystyczny [GUS]. 2022. Ochrona Środowiska. Warszawa.
11. Halecki W., Klatka S. 2017. Translocation of trace elements from sewage sludge amendments to plants in a reclaimed area. Bulletin of Environmental Contamination and Toxicology, 99, 239–243.
12. Halecki W., Klatka S. 2018. Long term growth of crop plants on experimental plots created among slag nr 1. heaps. Ecotoxicology and Environmental Safety, 147, 86–92.
13. Jurczyk Ł., Koc-Jurczyk J. 2014. Changes in the approach to waste disposal and generation of the leachate. Arch. Gosp. Odpad. Ochr. Środ., 16(1), 31–40.
14. Klatka S., Malec M., Ryczek M., Boroń K. 2015. Influence of mine activity of the coal mine "Ruch Borynia" on water management of chosen soils on mining area (in Polish). Acta Scientiarum Polonorum Formatio Circumiectus, 14(10), 115–125.
15. Klatka S., Malec M., Ryczek M., Kruk E., Zając E. 2016. Evaluation of retention ability of chosen industrial wastes (in Polish). Acta Scientiarum Polonorum Formatio Circumiectus, 15(4), 53–60.
16. Kowalik P. 1972. Theoretical basis of soil water potential measurements / Podstawy teoretyczne pomiarów potencjału wody glebowej (in Polish). Probl. Agrofiz., 2, 5–46.
17. Łabętowicz J., Stępień W., Kobiałak M. 2019. Innovative waste treatment technologies for agroecological utility fertilizers. Ecological Engineering & Environmental Technology, 20(1), 13–23.
18. Mocek A. 2015. Soil Science (in Polish). Wydawnictwo Naukowe PWN, Warszawa.
19. Mocek A., Drzymała S., Moszner P. 1997. Genesis, analysis and classification of soils (in Polish). Wydawnictwo AR, Poznań.
20. Mayo A., Pabhakar-Fox A., Meffre S., Cooke D.R. 2023. Alkaline industrial wastes – Characteristics, environmental risks, and potential for mine waste management. Environ. Pollut., 323, 121292.
21. Namiernik J., Łukasiak J., Jamrógiewicz Z. 1995. Collection of environmental samples for analysis (in Polish). Wydawnictwo Naukowe PWN, Warszawa.
22. Rozporządzenie Ministra Środowiska z dnia 1 września 2016 r. w sprawie sposobu prowadzenia oceny zanieczyszczenia powierzchni ziemi [Dz.U. 2016 poz. 1395].
23. Ryczek M., Boroń K., Klatka S. 2007. Effect of organic additives on hydraulic properties of selected industrial wastes (in Polish). Ochr. Środ. Zasob. Natur., 33, 93–96.
24. Sas-Nowosielska A., Kucharski R., Kuperberg J.M., 2010. Phytoremediation of soils around former zinc and lead facilities. In: G. Plaza (Ed.). Trends in bioremediation and phytoremediation. Kerala: Research Signpost, 373–381.
25. Soil Survey Division Staff 1993. Soil Survey Manual. Soil Conservation Service. U.S. Department of Agriculture Handbook, 18.
26. Strzyszcz Z., Łukasik A. 2008. Principles of using a variety of wastes for biological reclamation of post-industrial sites in Silesia (in Polish). Gosp. Odpad., 24(2/3), 41–49.
27. Szafrański C., Stachowski P., Kozaczyk P. 2011. Actual condition and forecast of improvement of water management is soil of post mining grounds (in Polish). Rocz. Ochr. Środ., 13, 485–510.
28. Ustawa z dnia 14 grudnia 2012 r. o odpadach z póź. zm. Dz.U.2023.1587
29. Wösten J.H.M., Van Genuchten M.Th. 1988. Division s-6-soil and water management and conservation. Soil Sci. Soc. AM. J., 52, 60.
30. Vega F.A., Covelo E. F., Andrade M.L. 2006. Competitive sorption and desorption of heavy metals in mine soils: Influence of mine soil characteristics. J. Colloid Interface Sci., 298, 582–592.