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The Influence of the Soil Type on the Permeability of Petroleum Derivatives

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1. Introduction

Petroleum substances are chemical substances obtained under the oil rectification, which results in fractions of different molecular sizes (Nazir 2011, Piecuch et al. 2015). The fractions emitted from crude oil are gasoline, aviation fuels, diesel oils, lubricating oils, lubricants, asphalt, waxes and bitumens (Iloeje & Aniago 2016, Skwarczynski & Skwarczynska-Kalamon 2016). Petroleum substances are non-polar, lithophilic and slightly soluble in water (Gitipour et al. 2016, Piecuch & Dabrowski 2014). They have strong toxic and carcinogenic properties, they are dangerous for human health and life and easily penetrate into the environment (Piecuch & Piecuch 2013, Głobińska et al. 2017).

The sources of incidents involving petroleum substances and the oil itself are industrial processes, including failures of processing and extraction installations, storage and transport such as rail, road (tank disasters), pipeline and water transport (Alimohammadi-Jelodar & Karimpour-Fard 2018). The most serious effects occur in events related to pipeline transport due to its location and the most common reason of leakage of petroleum-derived substances from pipelines, is the theft of transported fuels, in particular gasoline. During the drilling of pipelines through thieves, there is an uncontrolled leakage of a substance that directly enters the ground and the aquatic environment (Streche et al. 2018, Piechota-Polanczyk et al. 2013). Additionally, crude products in Poland account for 91% of substances transported by land (Piechota-Polanczyk et al. 2018, Kowalska et al. 2018).

The dominant soils in Poland are brown and ground soils. The map of Polish soils has been divided into zone, non-zone, inter-zone and non-zonal soils (Uznije & Agunwamba 2011). The diversity of parent rocks cause the occurrence of not one, but several types of zone soils that make up the soil cover of Poland. They occupy 75% of the country's territory, and their representatives are brown soils, which constitute 50% of the country's surface, podzolic soil that constitutes about 26% of the area, rusty soils occupying 14% of the area, podzolic soils occupying about 10%. A representative of non-zone soils is a black earth, occupying about 1% of the total area of the country. Intra-zone soils occupy less than 25% of the country's surface, lining the bottoms of river valleys (Piechota-Polanczyk & Gorąca 2012). Their representatives are river rivers covering 5% of Poland, hydrogenic soils constituting 7.8% of the country's territory, peat soils occupying 6.5% of the country, black earth constituting about 1% of the country's surface and rendzinas occupying about 0.9% of the area. Non-zoned soils are works that do not have a well-developed soil profile (Piechota & Goraca 2011).

The water permeability of soils is defined as the amount of water soaked by a given cross-section of soil, at a given time, per unit of hydraulic slope. The measure of permeability is the permeability coefficient, which depends on the properties of the test medium. In laboratory tests, the liquid used during tests, the research method adopted and the calculation algorithm play a significant role in the filtration coefficient (Streche 2018). There are many methods for testing soil permeability: "Paramex" method – modeled on observations of water table fluctuations in hydrogenic holes caused by earthquakes ("ibid" 129); The "Slug test" method is based on the measurement of the speed of water state changes in the piezometer due to its inflow from the aquifer. Another method of water permeability is the Kamieński's pipe method, which allows a simple and quick determination of the approximate value of the soil filtration coefficient. It consists in measuring the speed of lowering the water table flowing through the studied soil at variable pressure of the water column.

The purpose of the work was to determine the influence of soil structure on the permeability of petroleum derivatives. The measurements were carried out on black earth and wetland soil using three petroleum substances, gasoline (95 octanes), diesel, used oil, and water as a reference liquid.

2. Materials and methods

2.1. Samples collection

The study on permeability of soils was carried out using Ostromęcki's method which allows to precisely determine the coefficient of soil permeability. The soil samples (wetland soil and black earth) were collected form lubuskie voivodship and placed in sealed containers.

Thanks to modifications, measurements can be made both in the field and in the laboratory using Ziemnicki's apparatus. Soil samples were taken up to Kopecky's cylinders with a capacity of 250 cm^3. The composition of Ziemnicki's apparatus includes: a liquid tank soaked through the soil, a dense grid under and over the soil sample. Each time 150 cm^3 of soil was analyzed. Next, to the weighted soil, 50 ml of tested liquid was added on the soil surface. The height "h", time of disappearance of the liquid mirror, total time of condensation and the amount of condensed substance were measured. The measurements continued with additional two volumes of liquid until the total of 150 ml was added. Measured parameters included permeability, permeability coefficient and capillary capacity. Permeability was calculated using the following equation (1):

$$P = V / (S \cdot t) \tag{1}$$

where:
P – soil unit permeability, [cm/s],
V – volume of liquid absorbed or soaked by S, [cm^3],
S – infiltration area, [cm^2],
t – total infiltration time, [s].

Permeability coefficient was calculated from the equation (2):

$$K_t = V / (S \cdot t \cdot i) \tag{2}$$

where:
K_t – coefficient of permeability,
S – infiltration area, [cm^2],
t – total infiltration time, [s],
i – drop in hydraulic pressure, i = h/l, [-],
h – the height of the liquid column in the cylinder,
counted from the bottom of the soil, [cm],
l – thickness of the soil layer, [cm].

Capillary capacity was calculated using equation (3):

$$P_k = (M_c - M_{c1}) / M_g \tag{3}$$

where:
P_k – capillary capacity of the tested soil, [g/g],
M_c – ass of liquid poured, [g],
M_{c1} – mass of liquid soaked, [g],
M_g – soil mass, [g].

All measurements were done in triplicates.

In the research gasoline 95 octanes, diesel and used oil were applied. The term “used oil” was used for the oil that was replaced from a car engine after one year of usage.

2.2. Statistical analysis

Data are presented as mean±standard error (SEM). Comparison between groups was performed using two-way ANOVA after verification of normality with Statistica 12.0 software. Data were considered statistically different when $p < 0.05$.

3. Results and discussion

The first analyzed parameter presented of Fig. 1 showed permeability of wetland soil and black earth for four liquids: water (as reference), gasoline, diesel and used oil. Permeability of water decreased with addition of subsequent volumes of liquid (Fig. 1A). Meanwhile, permeability of gasoline, diesel and used oil increased significantly with each added volume (Fig. 1A, $p < 0.001$). Interestingly, permeability of used oil was over 20-times lower comparing to gasoline and petrol tested in the same conditions (Fig. 1A, $p < 0.001$).
The results for the second tested soil, black earth, indicated that permeability for gasoline increased over 5-times with the second addition of 50 ml of gasoline ($p < 0.001$, Fig. 1B). Similarly, permeability for diesel and used oil showed similar pattern causing 3-time rise for gasoline ($p < 0.001$) and 4-time increase for water ($p < 0.001$, Fig. 1B).

Second analyzed parameter was permeability coefficient depicted on Fig. 2. Similarly, to results on Fig. 1 we observed a significant decrease of permeability coefficient for water in both wetland soil (Fig. 2A) and black earth (Fig. 2B) as well as an increase for gasoline ($p < 0.001$), diesel ($p < 0.001$) and used oil ($p < 0.001$) (Fig. 2).

Capillary capacity presented on Fig. 3 indicated that at the beginning gasoline and diesel capillary capacity was significantly lower compared to water ($p < 0.001$) for wetland soil (Fig. 3A) but not for black earth where gasoline capillary capacity was even higher compared to water ($p < 0.01$; Fig. 3B). Addition of subsequent volumes of liquid significantly decreased capillary capacity for all tested liquids in both soils type (Fig. 3). Additionally, capillary capacity for wetland soil was as low as zero when the third volume of diesel and used oil was added (Fig. 3A).

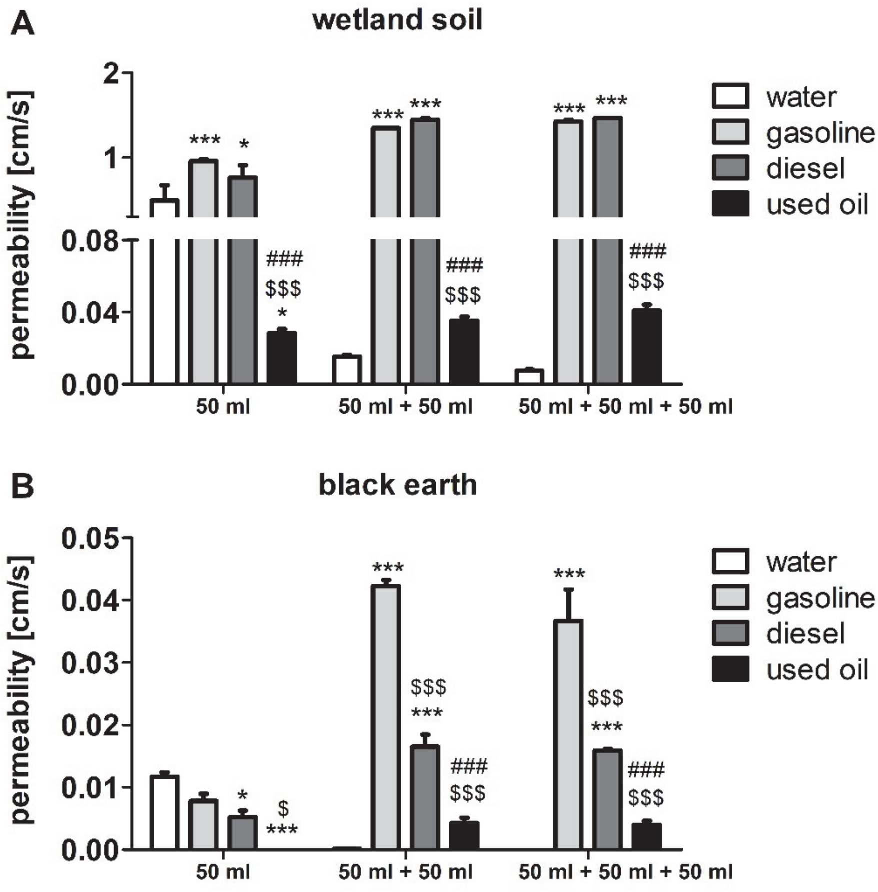

Fig. 1. Permeability of wetland soil (A) and black earth (B) for water, gasoline, diesel and used oil in the volume of 50 ml added subsequently to the total of three repetitions. Data are presented as mean±SEM. *p < 0.05; **p < 0.01, ***p < 0.001 vs water, ###p < 0.001 vs diesel; $p < 0.05; $$p < 0.01; $$$p < 0.001 vs gasoline

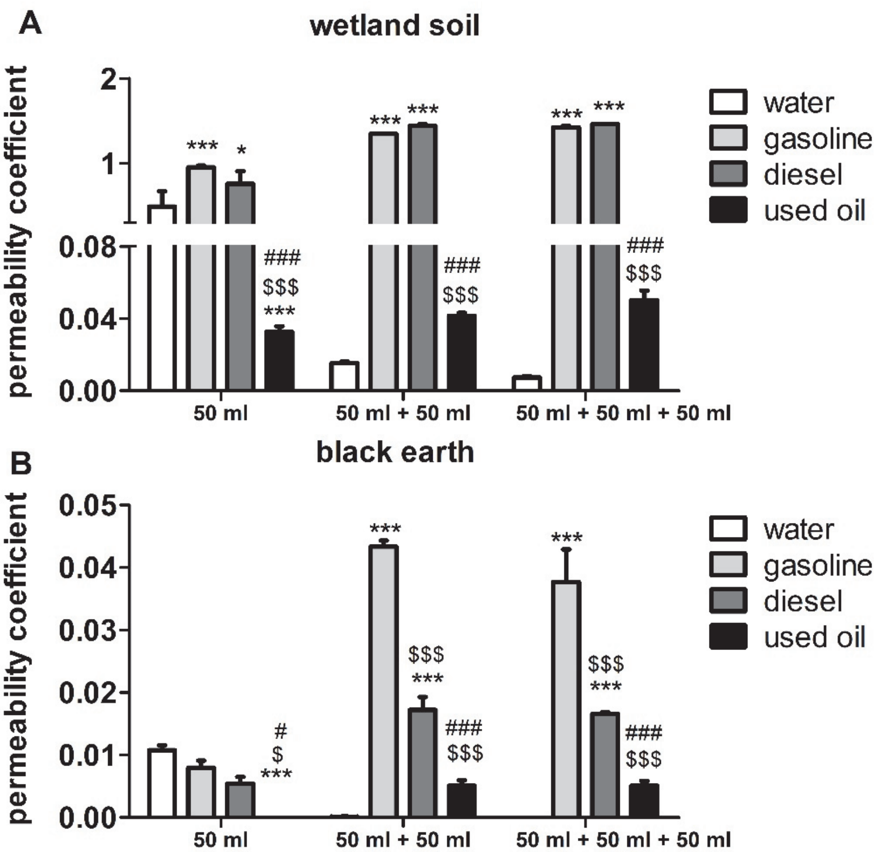

Fig. 2. Permeability coefficient of wetland soil (A) and black earth (B) for water, gasoline, diesel and used oil in the volume of 50 ml added subsequently to the total of three repetitions. Data are presented as mean±SEM. ***p < 0.001 vs water, #p < 0.05, ###p < 0.001 vs diesel; $$$p < 0.001 vs gasoline

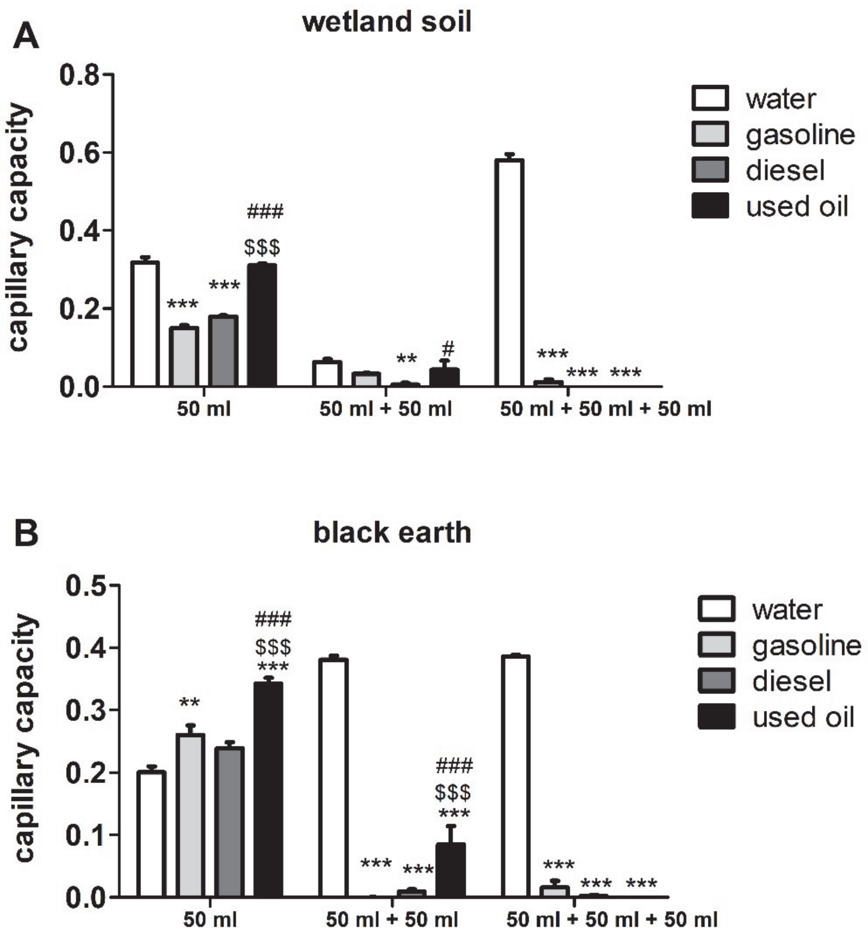

Fig. 3. Capillary capacity of wetland soil (A) and black earth (B) for water, gasoline, diesel and used oil in the volume of 50 ml added subsequently to the total of three repetitions. Data are presented as mean±SEM. $^{**}p < 0.01$, $^{***}p < 0.001$ vs water, ###$p < 0.001$ vs diesel; \$\$\$$p < 0.001$ vs gasoline

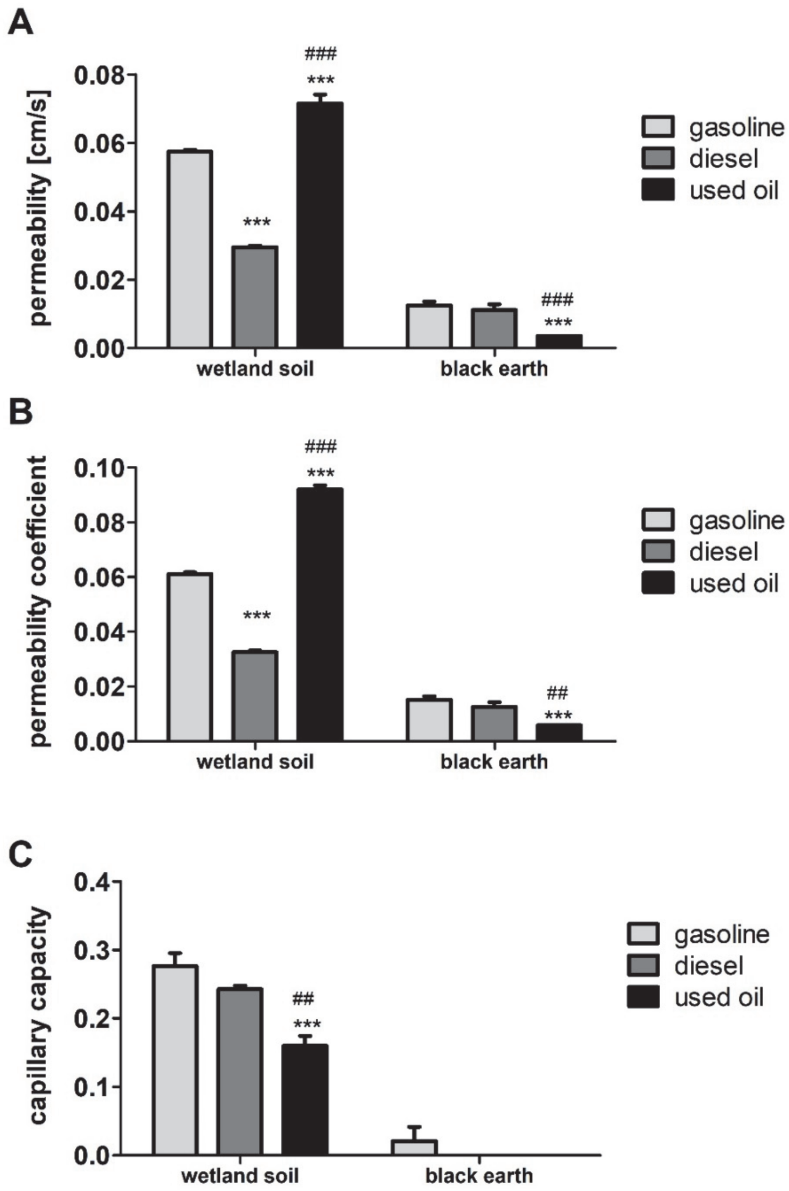

Fig. 4. The influence of experimental rain conditions on soil permeability (A), permeability coefficient (B) and capillary capacity (C) for gasoline, diesel and used oil. Data are presented as mean±SEM. ***$p < 0.001$ vs gasoline, ##$p < 0.01$, ###$p < 0.001$ vs diesel

Finally, comparison of wetland soil and black earth soils presented in Fig. 4 indicated that permeability, permeability coefficient and capillary capacity was 2-5-times higher for wetland soil compared to black earth for all tested liquids. The highest value of permeability and permeability coefficient was observed for used oil for wetland soil (Fig. 4a-B) but not for black earth where this fluid had the lowest values of analyzing parameters comparing to gasoline and diesel ($p < 0.001$, Fig. 4). Diesel and gasoline had similar permeability, permeability coefficient and capillary capacity on black earth but not on wetland soil where diesel had lower permeability compared to gasoline ($p > 0.05$, Fig. 4).

These results are in line with, Li et al. who presented that soil permeability can be changed when the soil is contaminated by oil pollutants, which can influence the transport of water or solute in the soil-water system (Li et al. 2009). In they paper Li et al. showed that soil polluted with crude oil had decreased permeability coefficient to the greater extent than diesel oil. Similar results were presented by Lopez et al. (2019).

4. Conclusions

This study aimed to determine the influence of soil structure on the permeability, permeability coefficient and capillary capacity wetland soil and black earth for gasoline, diesel and used oil using water as a reference liquid. The results indicated that permeability of gasoline, diesel and used oil increased significantly with each added volume while permeability of used oil was over 20-times lower comparing to gasoline and petrol tested in the same conditions. Meanwhile for black earth permeability of all tested fluids increased compared to water. Similar results was observed for permeability coefficient. Furthermore, capillary coefficient for wetland soil was lower for all tested liquids compared to water and it decreased with each added volume. On the contrary capillary coefficient for black earth was higher compared to water after adding of first volume of liquids but it decreased when additional volumes were added. Therefore, the results indicated that permeability of wetland soil is higher compared to black earth in case of gasoline and diesel but not used oil. Interestingly, permeability of black earth for diesel was markedly lower compared to wetland soil.

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Abstract

Petroleum substances are non-polar, lithophilic and very slightly soluble in water. They have strong toxic and carcinogenic properties, they are dangerous for human health and life; they easily get into the environment. The sources of incidents involving petroleum substances and the oil itself are industrial processes, including failures of processing and extraction installations, storage and transport, which includes rail, road (tank disasters), pipeline and water transport. Often there is an uncontrolled leakage of a substance that directly enters the ground and the aquatic environment. The dominant soils in Poland are brown and ground soils. The water permeability of soils is defined as the amount of water soaked by a given cross-section of soil, at a given time, per unit of hydraulic slope. The measure of permeability is the permeability coefficient, which depends on the properties of the test medium.

This study aimed to determine the influence of soil structure on the permeability, permeability coefficient and capillary capacity wetland soil and black earth for gasoline, diesel and used oil using water as a reference liquid.

The study on permeability of soils was carried out using Ostromęcki's method and Ziemnicki's apparatus. The soil samples (wetland soil and black earth) were collected form lubuskie voivodship. Each time 150cm^3 of soil was analyzed. Next, 50 ml of tested liquid was added on the soil surface and soaking time was recorded. The action was repeated 3 times to the total of 150 ml of tested fluid. Measured parameters included permeability, permeability coefficient and capillary capacity.

Permeability of gasoline, diesel and used oil increased significantly with each added volume ($p < 0.001$). While permeability of used oil was over 20-times lower comparing to gasoline and petrol tested in the same conditions ($p < 0.001$). The results for black earth, indicated that permeability for gasoline increased over 5-times with the second addition of 50 ml of gasoline ($p < 0.001$) and permeability for diesel and used oil lead to 3-time rise for gasoline ($p < 0.001$) and 4-time increase for water ($p < 0.001$). Analysis of capillary capacity showed that at the beginning gasoline and diesel capillary capacity was significantly lower compared to water ($p < 0.001$) for wetland soil but not for black earth where gasoline capillary capacity was even higher compared to water ($p < 0.01$). Addition of subsequent volumes of liquid significantly decreased capillary capacity for all tested liquids in both soils type. Furthermore, comparison of wetland soil and black earth soils indicated that permeability, permeability coefficient and capillary capacity was 2-5-times higher for wetland soil compared to black earth for all tested liquids.

The results indicated that permeability of wetland soil is higher compared to black earth in case of gasoline and diesel but not used oil. Interestingly, permeability of black earth for diesel was markedly lower compared to wetland soil.

Keywords:
permeability, permeability coefficient, capillary capacity, permeability of petroleum, permeability of soils

Przepuszczalność różnych typów ziemi w kontakcie z wybranymi substancjami ropopochodnymi, spotykanymi w akcjach ratowniczych Państwowej Straży Pożarnej

Streszczenie

Substancje ropopochodne są niepolarne, litofilne i bardzo słabo rozpuszczalne w wodzie. Mają silne właściwości toksyczne i rakotwórcze, są niebezpieczne dla ludzkiego zdrowia i życia; łatwo dostają się do środowiska. Źródłem wypadków z udziałem substancji ropopochodnych i samej ropy naftowej są procesy przemysłowe, w tym awarie instalacji przetwórczych i wydobywczych, magazynowania i transportu, które obejmują transport kolejowy, drogowy (katastrofy czołgowe), transport rurociągowy i wodny.

Często dochodzi do niekontrolowanego wycieku substancji bezpośrednio do ziemi i środowiska wodnego.

Dominującymi glebami w Polsce są gleby brunatne i gruntowe. Przepuszczalność wodną gleb definiuje się, jako ilość wody przesiąkniętej przez dany przekrój gleby, w określonym czasie, na jednostkę spadku hydraulicznego Miarą przepuszczalności jest współczynnik przepuszczalności, który zależy od właściwości badanego ośrodka.

Celem tego badania było określenie wpływu struktury gleby na przepuszczalność, współczynnik przepuszczalności i pojemność kapilarną gleby bagiennej i czarnoziemu dla benzyny, oleju napędowego i przepracowanego oleju przy użyciu wody jako cieczy referencyjnej.

Badanie przepuszczalności gleb przeprowadzono metodą Ostromęckiego i aparatem Ziemnickiego. Próbki gleby (bagiennej I czarnoziemu) pobrano z województwa lubuskiego. Za każdym razem analizowano 150 cm^3 gleby. Następnie dodano 50 ml badanej cieczy na powierzchnię gleby i zarejestrowano czas namaczania. Czynność powtórzono 3 razy do całkowitej objętości badanego płynu wynoszącej 150 ml. Zmierzone parametry obejmowały: przepuszczalność, współczynnik przepuszczalności i pojemność kapilarną. Przepuszczalność benzyny, oleju napędowego i zużytego oleju znacznie wzrosła z każdą dodaną objętością ($p < 0{,}001$). Przepuszczalność zużytego oleju była ponad 20-krotnie niższa w porównaniu z benzyną i benzyną badaną w tych samych warunkach ($p < 0{,}001$). Wyniki dla czarnoziemu wskazują, że przepuszczalność benzyny wzrosła ponad 5-krotnie przy drugim dodaniu 50 ml benzyny ($p < 0{,}001$), a przepuszczalność dla oleju napędowego i zużytego oleju wykazała 3-krotny wzrost dla benzyny ($p < 0{,}001$) i 4-krotny wzrost dla wody ($p < 0{,}001$). Analiza pojemności kapilarnej wykazała, że na początku była ona znacznie niższa dla benzyny i oleju napędowego w porównaniu z wodą ($p < 0{,}001$) dla gleby bagiennej, ale nie dla czarnoziemu, gdzie pojemność kapilarna benzyny była nawet wyższa w porównaniu z wodą ($p < 0{,}01$). Dodanie kolejnych objętości cieczy znacząco zmniejszyło pojemność kapilarną dla wszystkich badanych cieczy w obu typach gleb. Ponadto porównanie gleby bagiennej i czarnoziemu wykazało, że przepuszczalność, współczynnik przepuszczalności i pojemność kapilarna były 2-5 razy wyższe dla gleby bagiennej w porównaniu z czarnoziemem dla wszystkich badanych cieczy.

Wyniki wskazują, że przepuszczalność gleby bagiennej jest wyższa w porównaniu z czarnoziemem w przypadku benzyny i oleju napędowego, ale nie zużytego oleju. Co ciekawe, przepuszczalność czarnoziemu dla oleju napędowego była znacznie niższa w porównaniu z glebą bagienną.

Słowa kluczowe
przesiąkliwość, współczynnik przesiąkliwości, pojemność kapilarna,
przesiąkliwość ropopochodnych, przesiąkliwość gleb