MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

Rocznik Ochrona Środowiska

Volume 22. Year 2020 ISSN 1506-218X 1084-1096

Computation of Filtration Bed Porosity Based on Selected Filtration Coefficient Equations by Application of Numerical Methods

Jacek Piekarski
Koszalin University of Technology, Poland
corresponding author's e-mail: jacek.piekarski@tu.koszalin.pl

1. Introduction

Gravitational filtration is a process of solid and liquid phase separation. Wastewater suspension conveyed to a porous bed makes a single-phase solution or is a mixture of solid impurities contained in liquid phase (Piecuch 1984, Piekarski 2004, Skoczko 2019). Stopping of such impurities is based on mechanical action of a filtration bed mostly through wedging of the solid phase in its pores (Rup 2006). However, the relationship between size of the solid phase fraction contained in wastewater and size of grains of the filtration bed is important because it determines the type of the process as gravitational filtration may proceed, among other things, on a porous bed, in the very porous bed, simultaneously on and in the porous bed, in the porous bed with a colmatation barrier and accumulated sediment layer etc. (Piecuch et al. 2013, Palica et al. 2001, Piekarski 2009).

Analysing a filtration process, based on the general balance equation, which assumes in simplified form that the suspension solid phase inflowing in volume Q_{SN} was stopped in the filtration bed pores and created a colmatation barrier in the filtration bed pores as well as developed a sediment on the bed and got into filtrate in amount of Q_{SF}, one can generally put it as follows (Piekarski 2009, Piekarski 2019):

$$\int_0^{Q_{SN}} dQ_{SN} - \int_0^{Q_{SF}} dQ_{SF} = A \cdot \rho_S \cdot \sum_i^n (L_i \cdot \int d\varepsilon_i) \tag{1}$$

Having put in equation (1) particular layers:

$$\beta_N \int_0^{V_N} dV_N - \beta_F \int_0^{V_F} dV_F = A \cdot \rho_S \cdot \left[L_Z \int_{\varepsilon_Z}^{\varepsilon_{Z0}} d\varepsilon_Z + L_K \int_{\varepsilon_K}^{\varepsilon_Z} d\varepsilon_K + L_O \int_{\varepsilon_O}^{1} d\varepsilon_O \right] \tag{2}$$

Hence equation (2) takes the following form:

$$\beta_N \cdot V_N - \beta_F \cdot V_F = A \cdot \rho_S \cdot \left[L_Z \cdot (\varepsilon_{Z0} - \varepsilon_Z) + L_K \cdot (\varepsilon_Z - \varepsilon_K) + L_O \cdot (1 - \varepsilon_O) \right] \tag{3}$$

It can be stated, based on equations (1) (2) (3), that the gravitational filtration process is a complex phenomenon and to provide possibly accurate characteristic of such process it is necessary to perform experiments within possibly broad range of parameters variability. Mathematical description of the gravitational filtration process requires determination of values of a number of parameters (Skoczko et al. 2016). This pertains to the presentation of the filtration barrier through determination (based on the grain size analysis) of sizes of characteristic diameters as well as the characteristic of medium flow through the filtration bed computing e.g. filtration or permeability coefficient values. The filtration coefficient is a feature specific for given bed and it depends on its porosity, grain size and flowing medium temperature. In practice, the filtration coefficient is being computed through application of laboratory methods, measurements performed in real terms or using any indirect methods based on empirical formulas. Of course, the methods based on physical medium flow through the bed take into account, in the most accurate way, impact of grain geometry and, in effect, impact of porosity on the filtration coefficient value. Some researches suggest that the difficulty in putting bed microstructure in analytical and empirical mathematical formulas results in unreliability of the results originating from it. However, it is a well known fact that bed microstructure has impact on the size and shape of the porous space determining its capability to retain bound and contact waters therein. Presence of such waters reduces volume of pores through which water could flow freely, therefore, it determines the effective porosity size (Parylak et al. 2013).

To compute values of the described gravitational filtration characteristic parameters my own computer software FILTRA was used (Piekarski 2011). This application is composed of a number of modules being separate subroutines. The first module for the so-called grain size analysis performs, based on initial data, computation of the grain size distribution curve and characteristic diameters. In the next step of this application operation the results of computation can be exported to a module associated with computation of the filtration coefficient and bed permeability. Consequently, the values computed in this module, i.e. filtration coefficient and bed permeability coefficient as well as values computed in the grain size analysis module i.e. characteristic diameters, can be exported to a subsequent module responsible for computation of medium flow through the porous layer or exported to a module associated with gravitational filtration process computation.

In this paper an interesting combination of a direct laboratory method and computational indirect method based on Slichter's analytical and empirical mathematical formula in order to determine variations in filtration bed porosity values has been presented using FILTRA application.

2. Methodology of research

One of the methods of measurement of filtration coefficient value K_L [m/s] is the direct laboratory method called the variable pressure method.

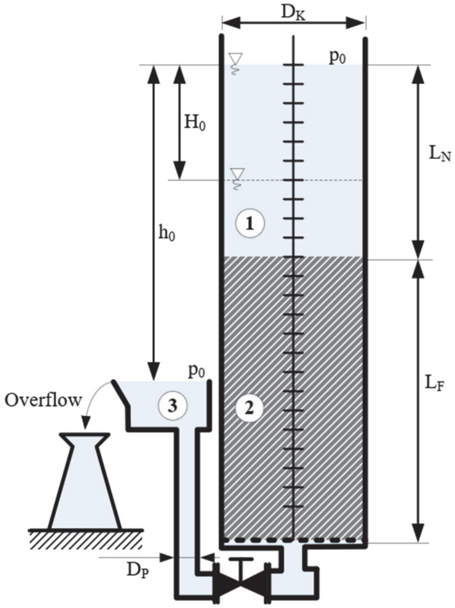

Fig. 1. Diagram of laboratory experimental stand for determination of filtration coefficient using method of variable pressure of medium (1 – medium; 2 – filtration bed; 3 – overflow tank)

This method takes into account height of filtration layer L_F [m], the distance between the upper medium level in the filtration column and the level in the overflow tank h_0 [m], downgrade of medium level H_0 [m] after time t_K [s] and filtration column diameter D_K [m] as well as the diameter of the pipe connecting it with the overflow tank D_P [m] (Piekarski 2009):

$$K_L = -t_K^{-1} \cdot D_P^2 \cdot D_K^{-2} \cdot L_F \cdot \mathrm{Ln}\left(1 - H_0 \cdot h_0^{-1}\right) \text{ [m/s]} \tag{4}$$

Indirect methods using empirical formulas can be divided, in terms of the input data type essential for filtration coefficient computation, into three groups, which take into account solely characteristic grain diameters (group I), characteristic grain diameters and bed porosity (group II), grain size distribution, bed porosity and physical properties of the flowing medium (group III). Slichter's formula, which belongs to group III is used to determine the filtration coefficient K_{SL} [m/d] of sand and gravel featuring diameter of $d_{10} \in <0.01$ mm-5.00 mm>:

$$K_{SL} = 88{,}3 \cdot m_{SL} \cdot \mu_{SL}^{-1} \cdot d_{10}^{2} \text{ [m/d]} \tag{5}$$

where:
μ_{SL} – coefficient of dynamic viscosity in CGS system, [P],
m_{SL} – analytical coefficient, [-].

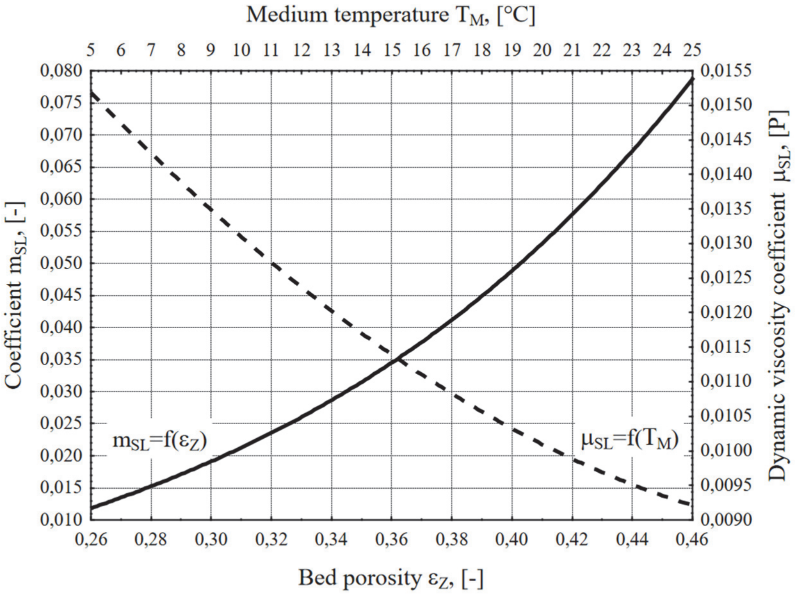

Fig. 2. Change of value of m_{SL} [-] coefficient against bed porosity ε_Z [-] and dynamic viscosity coefficient μ_{SL} [P] against medium temperature T_M [°C]

Value of coefficient m_{SL} [-] in formula (5) pertaining to bed porosity $\varepsilon_{SL} \in <0.26-0.46>$ can be calculated from the following equation (Figure 1):

$$m_{SL} = 2.108 \cdot \varepsilon_{SL}^{3} - 1.199 \cdot \varepsilon_{SL}^{2} + 0.357 \cdot \varepsilon_{SL} - 0.037 \text{ [-]} \tag{6}$$

where:
ε_{SL} – bed porosity in the Slichter's formula, [-].

However, dynamic viscosity coefficient value μ_{SL} [P] in formula (5) pertaining to water temperature $T_M \in <5\text{-}25^{o}C>$ can be calculated from the following equation (Figure 1):

$$\mu_{SL} = 2.72E\text{-}8\cdot T_M^3+6.79E\text{-}6\cdot T_M^2-5.24E\text{-}4\cdot T_M+1.76E\text{-}2\ [P] \tag{7}$$

where:
T_M – water temperature [^{o}C].

Transformation of formula (5) into a form making possible computation of bed porosity results in its excessive complexity. In order to avoid use of artificial neural networks (Wartalska 2020, Dawidowicz 2018, Dawidowicz et al 2018) the best method for solving of such computational problem is application of the iteration method. Therefore, assuming that value of the filtration coefficient computed from application of the variable pressure laboratory method (4) is equal to the value obtained from Slichter's empirical formula (5) i.e. $K_L = K_{SL}$ the value of filtration bed porosity ε_{SL} can be computed. A fragment of source code entered into FILTRA application algorithm (Piekarski 2011), making possible computation of porosity value ε_Z using Slichter's empirical formula (5), is presented in the below source code:

```
...
εi : =  0.26; εSL: = 0.26; i : =  0.0001;
Repeat
  εi: = εi+i;
  PSlichter(d10, εi, Tm, vmi0, mSL, KSL);
  if (KSL > =  KL) and (KSL>0) then εSL: = εi;
Until εi > =  0.46;
...
```

Due to formula (5) the initial value of bed porosity is $\varepsilon_i = 0.26$. Operation of filtration bed porosity value ε_i increase was repeated by the so-called counter, value of which reflected accuracy of computation (i = 0.0001). Lower value of the counter resulted in reduction of application speed but provided more accurate results. Then, using PSlichter's procedure filtration coefficient value was being computed based on the Slichter's formula (5)(6)(7). Computation was performed until the final condition i.e. getting of such bed porosity value ε_i, at which filtration coefficient value K_{SL} computed from formula (5) would be equal to or slightly higher (considering counter value) than the filtration coefficient value computed based on the variable pressure method K_L (4), was effected. The top iteration limit was the maximum value of applicability of formula (5), i.e. $\varepsilon_i = 0.46$.

During the laboratory tests filtration material featuring total mass of 1000g was prepared; it was then subjected to the grain size analysis, computing values of characteristic diameters i.e.: d_{10}, d_{20}, d_{60}, reliable d_M and modal d_{MO} as well as medial d_{ME}. The filtration bed was each time flushed/rinsed and put in a water filled column featuring diameter of $D_K = 5$ cm up to height of $L_F = 30$ cm. A cut-off valve was located in the bottom part of the filtration column on a pipe featuring diameter $D_P = 1.6$ cm, which connected the bed with the overflow tank (Fig.1). Water featuring temperature of $T_W = 21°C$ was fed in portions to the column at the medium-table height $L_N = 17$ cm above the filtration bed. The difference between the initial water-table height in the column and in the overflow tank was $h_0 = 36$ cm. During the test time t_K [s] of water-table downgrade in the filtration column at height of $H_0 = 13$ cm for three different filtration bed fractions was measured. Figures obtained were put into FILTRA, which resulted in values of filtration coefficient obtained through application of the variable pressure method K_L [m/s] and also using various analytical and empirical mathematical formulas, among other those proposed by Slichter K_{SL} [m/s].

3. Test results and interpretation

Filtration beds used in porosity testing were made of silica sand used for water purification in a way presented in Table 1.

Table 1. Filtration beds grain size characteristic

Pos.	Diameter d [mm]		Class weight, g_i [g]		
	min	max	Z_I	Z_{II}	Z_{III}
1	0.00	0.40	150	150	150
2	0.40	0.50	200	180	160
3	0.50	0.63	300	200	150
4	0.63	0.80	150	250	350
5	0.80	1.00	100	150	120
6	1.00	1.25	50	50	50
7	1.25	2.00	50	20	20

The data presented in Table 1 was entered into FILTRA, which resulted in production of mass fraction graphs $f_N(d_i)$ and summary mass fraction $F_N(d_i)$ depending on substitute diameter d_i [mm] taking into account modal diameter d_{MO}, medial diameter d_{ME}, reliable diameter d_M and d_{10}, d_{20} and d_{60} (Fig. 3).

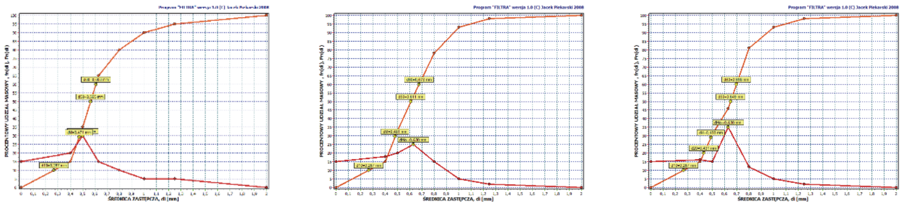

Fig. 3. Curves of mass fraction $f_N(d_i)$ and total mass fraction $F_N(d_i)$ depending on value of substitute diameter d_i [mm] taking into account modal diameter d_{MO}, medial d_{ME}, weighted particles diameter d_M, d_{10}, d_{20}, d_{60} Z_I, Z_{II} and Z_{III} filter beds

Based on the grain size analysis performed for the tested filtration beds (Figure 3) it can be stated that modal diameter (so-called dominant) d_{MO} reflecting the maximum of the mass fraction curve $f_N(d_i)$ is from 500 μm for bed Z_I and 630 μm for beds Z_{II} and Z_{III}. The medial diameter (so-called median) d_{ME} equal to 50% of the mass fraction varies from 565 μm (Z_I), through 611 μm (Z_{II}) to 649 μm (Z_{III}). Values of the grain reliable diameter d_M are 471 μm (Z_I), 481 μm (Z_{II}) and 488 μm (Z_{III}). The remaining characteristic values are for d_{20}: 425 μm (Z_I), 428 μm (Z_{II}) and 431 μm (Z_{III}) and for d_{60}: 608 μm (Z_I), 678 μm (Z_{II}) and 698 μm (Z_{III}) respectively. Due to applied formula (5) the most important is diameter d_{10}, value of which in the case of the tested filtration beds (Z_I, Z_{II}, Z_{III}) is 267 μm. The coefficient of grain size nonuniformity U [-] expressed as a quotient of diameters d_{60} and d_{10} respectively varies from 2.28 (Z_I), through 2.54 (Z_{II}) to 2.62 (Z_{III}). Based on temperature T = 21°C of water fed in portions and equation (7) the computed value of the dynamic viscosity coefficient is μ_{SL} = 9.88E-3 P, which in SI system is equivalent to μ_{SL} = 9.88E-4 Pa·s value.

Table 2. Test results for impact of variation in grain fractions size on porosity of three different filtration beds

Pos.	Bed	Water-table downgrade time	Filtration coefficient	Coefficient in equation (6)	Bed porosity
		t_K	$K_L = K_{SL}$	m_{SL}	ε_{SL}
		[s]	[m/s]	[-]	[%]
1	Z_I	54	2.55E-4	34.64E-3	36
2	Z_{II}	43	3.20E-4	43.39E-3	39
3	Z_{III}	38	3.62E-4	49.08E-3	40

Based on the results presented in Table 2 it can be stated that in the case of tested filtration beds Z_I, Z_{II} and Z_{III} during analysis of the filtration coefficient by application of the variable pressure laboratory method, the time of water-table downgrade t_K changes within the range from 38 s to 54 s. Based on formula (4) the computed value of filtration coefficient K_L varies from 3.62E-4 m/s to 2.55E-4 m/s. Change of values of the presented resultant variables is associated with differing grain size distribution of particular filtration beds (Table 1), which results, in particular, in variable porosity ε_{SL} within the range from 36 % to 40%.

As it appears from my research work, due to application of the first or second degree polynomial regression, equations determining the change of bed porosity value ε_{SL} can be obtained depending on the variation of the considered independent variables parameters such as, for example, characteristic diameter d_{60}, medial diameter d_{ME}, reliable diameter d_M or the coefficient of grain size non-uniformity U – see Figs 4 and 5. Quality of such approximation described by the correlation coefficient is close to 1, which confirms very good fitting of the obtained equations to the measurement points.

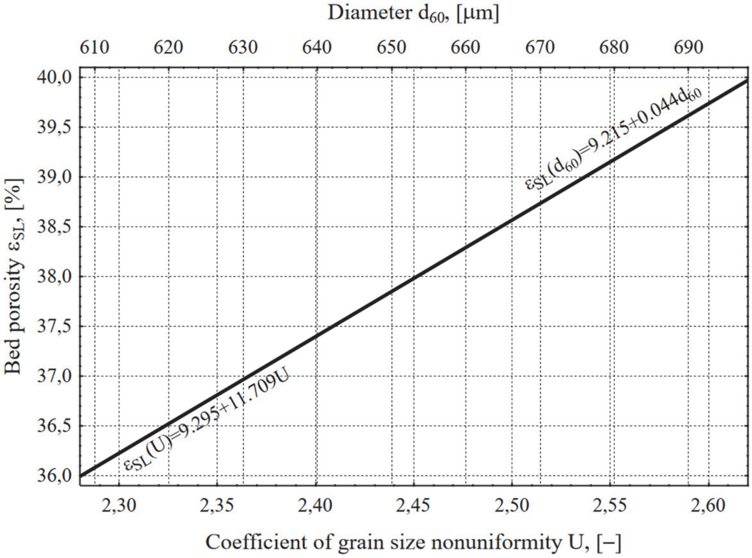

Fig. 4. Change of value of bed porosity ε_{SL} [%] depending on characteristic diameter value d_{60} [µm] and on coefficient of grain size nonuniformity U [-] of tested filtration beds Z_I, Z_{II} and Z_{III}

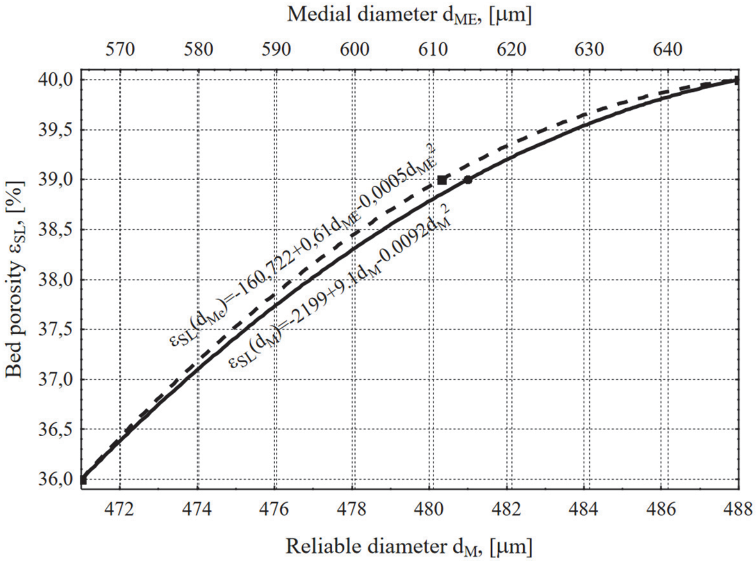

Fig. 5. Change of value of bed porosity ε_{SL} [%] depending on characteristic reliable diameter d_M [µm] and medial diameter d_{ME} [µm] values of tested filtration beds Z_I, Z_{II} and Z_{III}

The change of bed porosity value ε_{SL} [%] depending on the change of diameter value d_{60} [µm] within the range of 608 µm to 698 µm, can be put as $\varepsilon_{SL}(d_{60}) = 9.215+0.044\cdot d_{60}$. Due to the coefficient of grain size nonuniformity U [-] the linear equation is defined within the range from 2.28 to 2.62 taking shape of: $\varepsilon_{SL}(U) = 9.252+11.709\cdot U$. However, the change of bed porosity value ε_{SL} [%] in function of the reliable diameter value d_M [µm] within the range from 471 µm to 488 µm, is described by the following relationship:
$\varepsilon_{SL}(d_M) = -2199+9.1\cdot d_M-0.0092\cdot d_M^2$. Taking into account medial diameter value d_{ME} [µm] within the range from 565 µm to 649 µm, the resultant parameter can be presented in the following form: $\varepsilon_{SL}(d_{ME}) = -160.722+0.61\cdot d_{ME}-0.0005\cdot d_{ME}^2$.

4. Conclusions

Based on the test performed it can be stated that:

- Due to combination of the direct variable pressure laboratory method and indirect method based on a mathematical analytical and empirical formula e.g. Slichter's formula, applied for computation of the filtration coefficient, porosity of a filtration bed can be determined. Krüger's formula can also be used in such type computation.

- Application of any iteration methods allows for computation of bed porosity without any necessity to transform complex formulas. In such type iteration computation FILTRA software was particularly useful.
- Mathematical and empirical formulas for computation of filtration bed porosity can be created with sufficient accuracy using polynomial regression.
- Filtration bed porosity analysis experiments should be performed in possibly broad range of independent parameters variability (d_{20}, d_{60}, d_M, d_{Me}, U) and such experiments should pertain to the change of bed porosity values during filtration process when, for example, wastewater suspension is used (equation 3).

Key to symbols

t_K –time of water level downgrade at height H_0, [s],
ρ_S – mass density of solid phase, [kg/m^3],
Q_{SN} – initial mass of solid phase, [kg],
Q_{SF} – mass of solid phase in filtrate, [kg],
V_F – volume of filtrate, [m^3],
V_N – volume of medium, [m^3],
h_0 – distance between upper level of medium in column and level in overflow tank, [m],
ε_K – porosity of solid phase colmatated in bed, [-],
ε_{Z0} – porosity of bed without colmatation, [-],
ε_O –porosity of sediment layer, [-],
ε_Z – porosity of bed with colmatation, [-],
ε_{SL} –porosity of bed in Slichter's formula, [-],
A – surface of bed, [m^2],
D_K – filtration column diameter, [m],
d_{ME} – medial diameter, [mm],
d_{MO} – modal diameter, [mm],
D_P – diameter of pipe connecting filtration column with overflow tank, [m],
d_{10}, d_{20}, d_{60} – characteristic diameters, [mm],
T_M – temperature of water, [°C],
K_L – filtration coefficient computed based on the variable pressure method, [m/s],
μ_{SL} – coefficient of dynamic viscosity in CGS system, [P],
U – coefficient of grain nonuniformity, [-],
m_{SL} – analytical coefficient, [-].
H_0 – downgrade of medium level after time t_K [m],
L_K – height of colmatated solids layer in bed, [m],
L_O – height of sediment layer, [m],
L_Z – height of porous bed, [m],
β_N – initial concentration of solids, [kg/m^3],
β_F – concentration of solids in filtrate, [kg/m^3].

References

Dawidowicz, J. (2018). A Method for Estimating the Diameter of Water Pipes Using Artificial Neural Networks of the Multilayer Perceptron Type. *Advances in Intelligent Systems Research, 146*, 50-53.

Dawidowicz J. (2018). Evaluation of a pressure head and pressure zones in water distribution systems by artificial neural networks. *Neural Computing & Application, 30*(8), 2531-2538.

Dawidowicz, J., Czapczuk, A., Piekarski, J. (2018). The Application of Artificial Neural Networks in the Assessment of Pressure Losses in Water Pipes in the Design of Water Distribution Systems, *Rocznik Ochrona Środowiska, 20*, 292-308.

Palica, M., Kocurek, J. (2001). *Wybrane zagadnienia teorii filtracji i kompresji osadów*. Wydawnictwo Politechniki Śląskiej.

Parylak, K., Zięba, Z., Bułdys, A., Witek, K. (2013). Weryfikacja wyznaczania współczynnika filtracji gruntów niespoistych za pomocą wzorów empirycznych w ujęciu ich mikrostruktury. *Architectura, 12*(2), 43-51.

Piecuch, T. (1984). *Studium teoretyczne procesu filtracji grawitacyjnej wraz z informacją o aktualnych problemach gospodarki wodnej i ściekowej*. Polskie Towarzystwo Nauk o Ziemi, Częstochowa.

Piecuch, T., Piekarski, J., Malatyńska, G. (2013). Filtration of mixtures forming compressible sediments. *Rocznik Ochrona Środowiska, 15*, 39-58.

Piecuch, T., Piekarski, J., Malatyńska, G. (2013). The Equation Describing the Filtration Process with Compressible Sediment Accumulation on a Filter Mesh, *Archives of Environmental Protection, 1*, 93-104.

Piekarski, J. (2004). *Wybrane przykłady obliczeń komputerowych zastosowanych w inżynierii środowiska*. Wydawnictwo Politechniki Koszalińskiej.

Piekarski, J. (2009). Analysis of selected parameters of colmatation in the process of gravitational filtration. *Rocznik Ochrona Środowiska, 11*, 421-437.

Piekarski, J. (2009). Investigations on colmatation during filtration process on the porous deposit. *Polish Journal of Environmental Studies, 10*, 51-56.

Piekarski, J. (2009). Colmatation blockage during gravitational filtration process of coal suspension on sand bed. *Mineral Resources Management, 25*, 121-133.

Piekarski, J. (2011). Application of Numerical Methods to Modelling of Gravitational Filtration Process. *Rocznik Ochrona Środowiska, 13*, 315-332.

Piekarski, J. (2019). Impact of Compression on Bed Porosity in Gravitational Filtration Process, *Rocznik Ochrona Środowiska, 21*, 1579-1588.

Rup, K. (2006). *Procesy przenoszenia zanieczyszczeń w środowisku naturalnym*. WNT.

Skoczko, I. (2019). *Filtracja wody w teorii i praktyce*. Monografie Komitetu Inżynierii Środowiska, *151*, Wydawnictwo PAN.

Skoczko, I., Piekutin, J., Szatyłowicz, E., Niedźwiecka, M. (2016). Removal of boron from groundwater by filtration through selected filter bed materials, *Rocznik Ochrona Środowiska, 18*(2), 861-872.

Wartalska, K., Kaźmierczak, B., Nowakowska, M., Kotowski A. (2020). Analysis of hyetographs for drainage system modeling. *Water, 12*(149), 1-21.

Abstract

Gravitational filtration is a process of solid and liquid phase separation. Wastewater suspension conveyed to a porous bed makes a single-phase solution or is a mixture of solid impurities contained in liquid phase. Stopping of such impurities is based on mechanical action of a filtration bed mostly through wedging of the solid phase in its pores. However, the relationship between size of the solid phase fraction contained in wastewater and size of grains of the filtration bed is important because it determines the type of the process as gravitational filtration may proceed, among other things, on a porous bed, in the very porous bed, simultaneously on and in the porous bed, in the porous bed with a colmatation barrier and accumulated sediment layer etc. Gravitational filtration process is a complex phenomenon and to provide possibly accurate characteristic of such process it is necessary to perform experiments within possibly broad range of parameters variability. Mathematical description of the gravitational filtration process requires determination of values of a number of parameters. This pertains to the presentation of the filtration barrier through determination (based on the grain size analysis) of sizes of characteristic diameters as well as the characteristic of medium flow through the filtration bed computing e.g. filtration or permeability coefficient values. The filtration coefficient is a feature specific for given bed and it depends on its porosity, grain size and flowing medium temperature. In this paper an interesting combination of a direct laboratory method and computational indirect method based on Slichter's analytical and empirical mathematical formula in order to determine variations in filtration bed porosity values has been presented using FILTRA application.

Keywords:
gravitational filtration, bed porosity, mathematical modelling

Obliczenia porowatości złoża filtracyjnego na podstawie wybranych równań współczynnika filtracji przy wykorzystaniu metod numerycznych

Streszczenie

Filtracja grawitacyjna to proces rozdziału fazy stałej od ciekłej. W warunkach rzeczywistych zawiesinowe ścieki kierowane na złoże porowate stanowią roztwór jednofazowy lub są mieszaniną zawartych w fazie ciekłej zanieczyszczeń stałych. Zatrzymywanie takich zanieczyszczeń polega na mechanicznym działaniu warstwy filtracyjnej przez najczęściej klinowanie w jej porach fazy stałej. Jednak stosunek wielkości frakcji fazy stałej zawartej w ściekach oraz wielkości uziarnienia złoża filtracyjnego jest na tyle istotny, gdyż determinuje rodzaj procesu, ponieważ filtracja grawitacyjna może zachodzić między innymi: na złożu porowatym, w samym złożu porowatym, jednocześnie na złożu i w złożu porowatym, w złożu porowatym z blokadą kolmatacyjną i przyrostem warstwy osadu, itd. Proces filtracji grawitacyjnej jest zjawiskiem złożonym i aby charakterystyka takiego procesu była możliwie dokładna, niezbędne są eksperymenty prowadzone w możliwie szerokim zakresie zmienności parametrów. Opis matematyczny procesu filtracji grawitacyjnej wymaga wyznaczenia wartości szeregu parametrów. Dotyczy to przedstawienia przegrody filtracyjnej, poprzez wyznaczenie na podstawie analizy granulometrycznej wielkości średnic charakterystycznych, jak również charakterystyki przepływu medium przez złoże filtracyjne obliczając np. wartości współczynników filtracji czy przepuszczalności. Współczynnik filtracji jest wielkością charakterystyczną dla danego złoża i zależy od jego porowatości, uziarnienia oraz temperatury przepływającego medium. W niniejszej publikacji korzystając z aplikacji FILTRA przedstawiono interesujące połączenie bezpośredniej metody laboratoryjnej oraz obliczeniowej metody pośredniej bazującej na formule matematycznej analityczno-empirycznej Slichtera w celu wyznaczenia zmian wartości porowatości złoża filtracyjnego.

Słowa kluczowe:
filtracja grawitacyjna, porowatość złoża, modelowanie matematyczne