

Changes of sand density impact on water filter backwashing

Wpływ zmian gęstości piasku na płukanie filtrów pospiesznych wody

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Media of rapid filters is the subject of abrasion and coverage by biofilm which partially is not removed during backwashing. The empirical tests done for predicting the optimal backwash intensity as a function of water temperature proved that in computing the sand expansion it is necessary to take into consideration not only changes of the grains' shape but also the density of sand grains as the result of growing biofilm.

Key words: filter backwashing, sand, biofilm, backwash intensity

Złoża pospiesznych filtrów piaskowych ścierają się i pokrywają z czasem biofilmem, który nie jest w całości usuwany w czasie płukania. Empiryczne testy wykonane w celu doboru optymalnej wielkości intensywności płukania w funkcji temperatury wody płucznej wykazały, że w obliczeniach wielkości ekspansji złoża należy uwzględnić nie tylko zmianę w czasie eksploatacji kształtu ziaren ale również ich gęstości, która wynika z obrastania ich biofilmem.

Słowa kluczowe: płukanie filtrów, piasek, biofilm, intensywność płukania

Introduction

A. Amirtharajah [3-7] was one of the first persons to describe rapid water filter run as being dependent on filter backwashing. Traditionally in the U.S.A., filters were backwashed by water alone. However, this kind of backwash is less efficient because fluidized grains almost do not collide one with another and only shear stress created along the grains' surface scours the deposit accumulated during the filter run. Owing to that, some additional processes have been developed, such as starting the media cleaning process from energetic surface wash by water under high pressure [14]; these processes are described elsewhere [10,14,22,34]. European technology of backwashing based on air scour first [50], followed by simultaneous backwash with water-air mixture [8], and completed by backwash with water, has proven to be the most efficient method because of the high efficiency of both air scour and air-water backwash [24,27,28,41]. At the end of a properly provided backwashing the water flowing out of the filters is clean but the grains remain covered with biofilm and mineral impurities [6]. When the backwash water inflow is shouting down, the fluidized

grains settle and some of biofilm is scoured to the water. This creates poor first filtration quality. To overcome this problem, one of the following operations can be performed [1,2,30,32]:

- the first filtrate can be discharged together with water after backwashing to treatment and then returned to the beginning of the raw water treatment or lost,
- coagulant or polyelectrolyte is added to the backwash water at the very end of the backwashing,
- the backwash completes with flow velocity below the minimum fluidization velocity [1,2].

As the result of the grains abrasion their shape is more spherical and sizes smaller, so the sphericity coefficient being for crash particles about 0.7 and for natural sand from 0.78 – 0.81 tends to rise even up to 0.98 [44]. Moreover they are covered by biofilm, which for not efficient air scour backwashing glues single grains into larger agglomerates of much lower density than the density the of original grains material. These large agglomerates are likely to be partially lost flowing out of the filters during the backwash. Changes of grains' size and shape impacts the expansion of the filter media during backwashing

by the water [13], which is a well-known phenomenon. However, many practicing engineers do not recognize that changes of grains density is also an important factor of filter media expansion during backwashing. This impact is investigated here.

Expansion of filter media

The expansion of fluidized filter media can be predicted from the Richardson-Zaki equation (1) [9,14,18,26,29]:

$$\frac{V}{V_s} = \varepsilon^n \quad (1)$$

in which v is the backwash intensity, v_s free sedimentation velocity, porosity of fluidized filter media, and n the exponent being a function of the Reynolds number Re_s for free sedimentation velocity. According to measurements carried out by T. Siwiec [45] for the temperature 13 °C, the exponent n can be described by equations (2) – (9) collected in Table 1. In Table 2, the equations developed by another authors for the exponent n from the equation (1) are divided into three parts. The part 1 consists of equation valid for strictly specified range of the Reynolds numbers. In the second part, the equations refer to any material of

Table 1. Equations for the exponent n from equation (1) according to measurements carried out by T. Siwiec [45]

The exponent n from equation (1) as a function of Re _s for different minerals			
$n=10,467 \cdot Re_s^{-0,2015}$	for antracite	Tadeusz Siwiec [45]	(2)
$n=8,384 \cdot Re_s^{-0,163}$	for barite		(3)
$n=6,928 \cdot Re_s^{-0,1464}$	for chalcedonit		(4)
$n=8,413 \cdot Re_s^{-0,1794}$	for diatomite		(5)
$n=8,192 \cdot Re_s^{-0,1598}$	for klinoptylolite		(6)
$n=10,480 \cdot Re_s^{-0,1999}$	for nevraco		(7)
$n=7,084 \cdot Re_s^{-0,1596}$	for sand		(8)
$n=10,212 \cdot Re_s^{-0,2111}$	for pyrolusite		(9)

Table 2. Equations for the exponent n from equation (1) according to the table first published in the monograph [45] based on the literature sources listed below

Equation or the value	for	source	No.
Equations for „n” valid for specified range of Re _s .			
$n=4,65$	$0,001 < Re_s < 2,0$	Wen, You [38]	(10)
$n=3,37$	$2,0 < Re_s < 500$		(11)
$n=2,35$	$Re_s > 500$		(12)
$n=3,17$	$Re_s < 60$	Muslu [28]	(13)
$n=4 \cdot Re_s^{-0,057}$	$60 < Re_s < 200$		(14)
$n=6,55 \cdot Re_s^{-0,15}$	$200 < Re_s < 6000$		(15)
$n=1,78$	$Re_s > 6000$		(16)
$n=4,35 \cdot Re_s^{-0,03}$	$0,2 < Re_s < 1,0$	Sholij, Johnson [31]	(17)
$n=4,45 \cdot Re_s^{-0,1}$	$1,0 < Re_s < 200$		(18)
$n=4,65$	$Re_s < 0,2$	Di Felice [14], Yang, Renken [50]	(19)
$n=4,45 \cdot Re_s^{-0,03}$	$0,2 < Re_s < 1,0$		(20)
$n=4,45 \cdot Re_s^{-0,1}$	$1,0 < Re_s < 500$		(21)
$n=2,4$	$Re_s > 500$		(22)
Equations valid for the whole range of Reynolds numbers applied for conventional parameters of rapid water filters backwashing.			
$n=(5,09+0,2309 \cdot Re_s^{0,877}) / (1+0,104 \cdot Re_s^{0,877})$	The whole range of Re _s applicable in backwashing practice	Yun et al. [39]	(23)
$n=(5,09+0,284 \cdot Re_s^{0,877}) / (1+0,104 \cdot Re_s^{0,877})$	As above	Limtrakul et al. [23]	(24)
$n=(4,8+0,420 \cdot Re_s^{0,75}) / (1+0,175 \cdot Re_s^{0,75})$	As above	Rove [31] (Mazzei et al. [25])	(25)
$n=(4,8 + 0,1032 \cdot Ar^{0,57}) / (0,175 \cdot Ar^{0,57} + 1)$	As above	Khan, Richardson (Epstein [16])	(26)
$n=(4,7+0,4112 \cdot Re_s^{0,75}) / (1+0,175 \cdot Re_s^{0,75})$	As above	Rowe (van Zessen et al.. [45])	(27)
Equations for particular minerals			
$n=5,758 \cdot Re_s^{-0,0541}$	for garnet	Muslu [35]	(28)
$n=4,991 \cdot Re_s^{-0,054}$	for sand		(29)
$n=3,940 \cdot Re_s^{-0,100}$	for balotynty		(30)
$n=7,110 \cdot Re_s^{-0,148}$	dla antracytu		(31)
$n=6,98 \cdot Re_s^{-0,170}$	dla polistyrenu		(32)

media grains and any range of the Reynolds numbers occurring during conventional water rapid filters backwashing. The final third part refers exclusively to specified minerals.

Purpose of the study

In winter, significant saving of backwash water can be achieved when backwash intensity is adjusted to water temperature [15-17]. In summer, the same procedure protects filter media against losing during backwash [23]. During backwashing the filter media grains change size and shape because of frequent abrasion, so we decided to verify the applicability of equations (1) – (32) for predicting

the proper backwash intensity of a large surface water filter plant in the South of Poland. The plant consisted of eight sand filters followed by GAC filters. The results of the experiments reported here refer exclusively to the sand filters.

Experimental setup

To properly adjust backwash water intensity some experiments have been conducted on a filtration column being of the horizontal cross section in a form of a square, of which the sides are 30 centimeters long. The column for testing fluidization of filter media grains should have a large horizontal cross section area in comparison with columns used for research on depth

filtration [49]. Samples of sand were collected along the whole height of the sand filter layer of one of the filters in a technical scale by inserting a pipe of a diameter 32 mm and creating a vacuum inside the pipe above the filter media to prevent losing sand grains when pulling the pipe out of the media. The filtration column was backwashed with water of three different temperatures t from which t = 13 °C was the temperature of tap water and temperatures t = 19 °C and t = 25 °C were reached by warming up water in a large tank for backwash water of a volume about 1 m³.

Primary experiments

The curve presenting sieve analysis as weight dry fraction versus particle diameter is presented in Fig. 1.

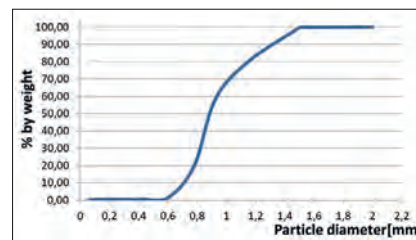


Fig. 1 Results of sieve analysis in the form of the weight fraction vs. particle diameter curve

Free settling velocities of particles in water were calculated for the representing diameter of each fraction from formulae known from the literature [25] and then fluidized bed porosity calculated for several equations (2) – (32) for n from equation (1). Finally, the total expansion of the whole sand filter bed was calculated as being the sum of each sand fractions' expansion. The expansion $E = (H-H_0)/H_0$ equals $(V-V_0)/V_0$ and can be calculated from eq. (33) [14-17].

$$(H-H_0)/H_0 = (1 - \epsilon_0) / (1 - \epsilon) - 1 \quad (33)$$

In eq. (33), H₀ and H are the initial and actual height of the fluidized filter media and ε₀ is the value of ε before fluidization. V and V₀ refer to the actual and initial volume of porous media. The experimental results of sand filter media fluidization are presented in Fig. 2.

The results of the calculations did not match the experimentally measured values so none of the equations (2) – (32) provided satisfactory results. The filter media has not been replaced for 8 years so the changes of sand grain's properties in time were suspected to be responsible for the disagreements. One of them is the coefficient of sphericity ψ defined as the ratio of

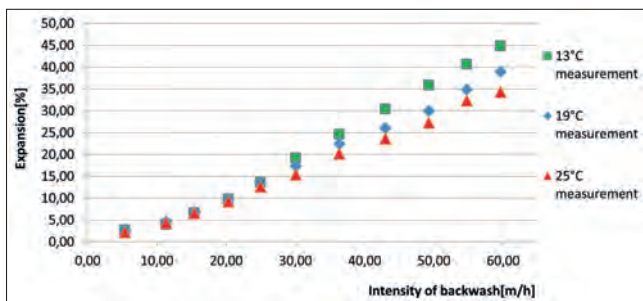


Fig. 2
Experimentally predicted expansion E of the sand filter media

filters has the intensities of backwashing resulting in expansion E between 15% and 30% [14] and eq. 8 gave the best fit to the measurements. Assuming that the measurements made in the laboratory were exactly accurate, the errors of computations are presented in Figs. 4,5,6.

Conclusions

Biofilm and trapped on sand grains impurities change the density of dry grains from old water rapid filters so significantly that this change has to be applied in the calculations of filter bed expansion. In spite of the fact that wet biofilm density differs

the ball surface having the same volume as the grain to the grain's surface. This coefficient does not appear directly either in the Richardson-Zaki equation (1) nor in eq. (2) – (32) for the exponent n from equation (1). However, free sedimentation velocity v_s depends indirectly on ψ as the Archimedes number Ar_s includes this coefficient and different formulae for n are used for different ranges of Ar_s and Re_s . Some modern definitions of Re_s contain this coefficient. Changing the value of ψ from 0.75 to 0.98 improved the results of the calculations a little, but they still remained unsatisfactory.

Quartz has a density of about 2,667 kg/m³ but in the case considered here the sand grains were covered with biofilm with organic and inorganic impurities. The average density of the dry grains was measured as equal to only 2,087 kg/m³. Using this value of density significantly improved the results of the calculations, making them sometimes accurate enough from the technical point of view. A comparison between the results of the computations and the laboratory measurements are presented in Fig. 3. The points denote experimental measurements and outlines

in the upper zone they gave the results close to the empirical results in a very narrow range of backwash intensity "u" – somewhere around 55m/h. For practical purposes, the backwash of rapid water

Fig. 4
The relative errors of the computed values of old sand filter media expansion for the exponent n calculated after T. Siwiec (8) [45]

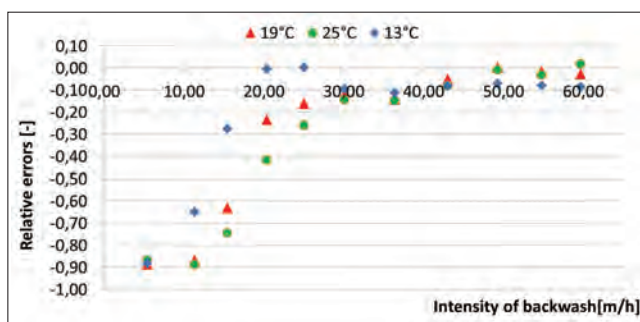


Fig. 5
The relative errors of the computed values of old sand filter media expansion for the exponent n calculated after Wen & Muslu (26)

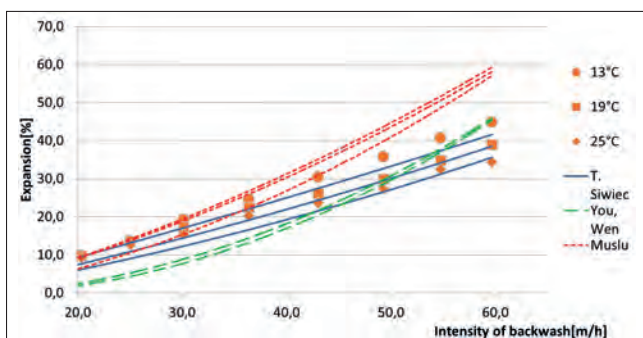
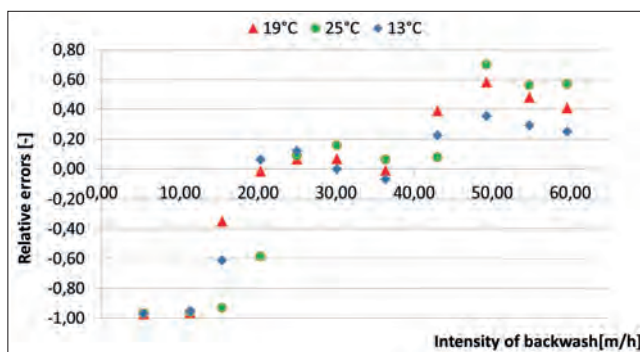


Fig. 3
A comparison between the experimentally measured expansion and results of the computations conducted according to the Richardson-Zaki equation (1) and to the three equations for n known from the literature

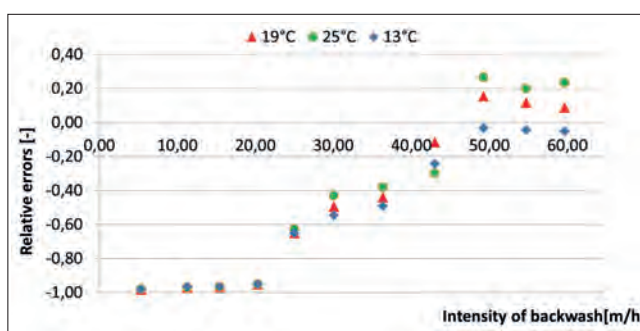
significantly from dry biofilm density, the equation (1) still appeared applicable for predicting the sand bed expansion for n calculated from Eq. (8) and the free sedimentation velocity calculated for the dry density of sand grains covered by biofilm.

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the results of the computations. The best fit of the theoretical curves to the results of the experiments was received for the whole range of backwash intensities from 20m/h to 60m/h for the equation developed by T. Siwiec [45], while the equation for n by Wen & Muslu (29) gave acceptable results only for the lower part of the intensities of backwash up to 35m/h while, contrarily, the equation for n by You (23) was highly inaccurate for low backwash intensities but

Fig. 6
The relative errors of the computed values of old sand filter media expansion for the exponent n calculated after You et al. (23)



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Zarządzanie strategiczne jako element minimalizacji ryzyka eksploatacją infrastruktury wodociągowej

Strategic management as an element of minimizing the operation risk of water supply infrastructure

IZABELA ZIMOCH, ŁUKASZ CZOPIK

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W artykule omówiono aktualne podejście do zarządzania przedsiębiorstwem wodociągowo – kanalizacyjnym oraz bieżące trendy w zarządzaniu. Wskazano elementy, które wymagają usprawnienia na przykładzie wybranych obszarów zarządzania w dużym przedsiębiorstwie wodociągowo – kanalizacyjnym. Skupiono się na wykazaniu, które czynniki i jakie podejście mają największy wpływ na zakłócenia w trakcie zarządzania tak specyficznym przedsiębiorstwem, jakim jest przedsiębiorstwo wodociągowo – kanalizacyjne. Wskazano możliwe narzędzia i metody wspomagające najwyższe kierownictwo w procesie zarządzania.

Słowa Kluczowe: Przedsiębiorstwo Wodociągowe – Kanalizacyjne, zarządzanie, zintegrowane systemy zarządzania, komunikacja w zarządzaniu, rozwiązania systemowe w zarządzaniu, zarządzanie projektami

The article describes the current approach to the management of a water supply and sewage company as well as current management trends. The elements which need improvement are indicated on the example of chosen areas in a large water supply and sewage company. The authors' focus was on demonstrating which factors and which approach have the biggest influence on disruptions in the management of such specific company as the water supply and sewage company. In this article possible tools and methods are proposed which can support the top management level in management process.

Key words: Water Supply and Sewage Company, management, integrated management systems, communication in management, system solutions in management, project management

Wprowadzenie

Klasyczne podejście do zarządzania przedsiębiorstwem wodociągowo – kanalizacyjnym charakteryzuje się skupieniem na działaniach kierowniczych. W typowym ujęciu jest to zbiór uszeregowanych w logiczny ciąg działań, które mają na celu świadczenie usług związanych z dostawą wody i odprowadzaniem ścieków. W ramach tych działań można wyodrębnić planowanie, organizację i koordynowanie, decydowanie i kierowanie, motywowanie, kontrolowanie [1]. Nauki o zarządzaniu i dostępna w tym zakresie literatura skupiają się na najistotniejszych branżach dla funkcjonowania gospodarki, czyli na branżach, które stanowią o jej konkurencyjności na rynku globalnym. Usługi komunalne pozostają, póki co poza głównym obszarem zainteresowań literatury nauk o zarządzaniu [2].

Zarządzanie operacyjne poprzez reagowanie na wystąpienie zakłócenia w systemie wodociągowym uznaje się za nieaktualną koncepcję. W dobie współczesnych rozwiązań powinno obowiązywać podejście zarządzania strategicznego, obejmującego działania prewencyjne wobec zagrożeń wywołanych zdarzeniami niepożądanymi [3]. Obserwuje się stopniowe zmiany w sposobie zarządzania przedsiębiorstwem wodociągowym. Widoczne jest przyjmowanie w sposobie zarządzania zaleceń Światowej Organizacji Zdrowia (World Health Organization, WHO) dotyczących zarządzania strategicznego. Zgodnie z tym podejściem prawidłowe zarządzanie systemem dystrybucji stanowi jedną z najistotniejszych barier ochronnych przeciw zanieczyszczeniu wody przeznaczonej do spożycia przez ludzi [4]. W krajowym prawodawstwie pojęcie oceny ryzyka dostaw wody pojawiło się w aktualnym Rozporządzeniu

Ministra Zdrowia w sprawie jakości wody przeznaczonej do spożycia przez ludzi, w którym została zdefiniowana jako proces polegający na identyfikacji zagrożeń i analizie ryzyka przeprowadzony na podstawie obowiązującej w czasie dokonywania tej oceny normy PN-EN 15975-2 „Bezpieczeństwo zaopatrzenia w wodę do spożycia – Wytyczne dotyczące zarządzania kryzysowego i ryzyka – Część 2: Zarządzanie ryzykiem” z uwzględnieniem jakości i rodzaju ujmowanej wody, zanieczyszczeń występujących w środowisku (z uwzględnieniem usytuowania ujęcia wody, ustanowionej strefy ochronnej ujęcia i oceny zagrożenia zdrowotnego dla tego ujęcia), zastosowanych technologii uzdatniania wody, długości sieci wodociągowej, materiałów użytych do budowy sieci wodociągowej, wieku wodociągu, sytuacji występowania epidemii wodopochodnych, aktualnych potrzeb i celów badań [5].

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